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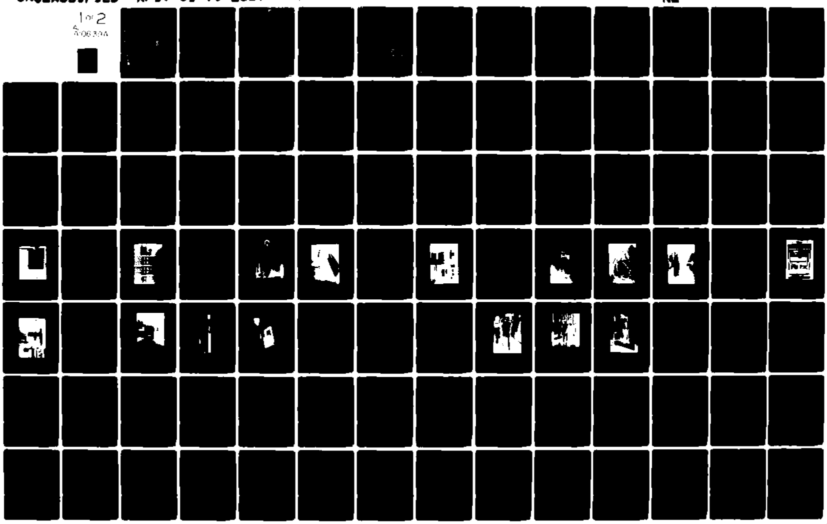

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Ph.D. THESIS DEFENSE ANNOUNCEMENTS

A Hybridization Analysis of a Complex Adaptation: Life-History Tactics in Lygaeus kalmii (Heteroptera: Lygaeidae)
Carl Kice Brown, Zoology
Prof. Hugh Dingle, Co-Ch.
Prof. Joseph Hegmann, Co-Ch.
March 27, 9:00 a.m., 239 ZB

A Comprehensive Performance Project in Percussion Literature with an Essay Comprised of Multi-percussion Performance Problems as Found in Selected Contemporary Works, with Original Etudes Relevant to Those Problems
Terry Lee Applebaum, Music
Prof. Thomas Davis, Co-Ch.
Prof. John Hill, Co-Ch.
March 28, 3:30 p.m., Music Library, 2000H MB

Two Dimensional Shape Optimal Design
Young Wha Chun, Mechanics & Hydraulics
Prof. Edward Haug, Ch.
March 29, 1:30 p.m., 1203 EB

Alternative Rings Whose Symmetric Elements Are Nilpotent or a Right Multiple is a Symmetric Idempotent
Gregory Peter Wene, Mathematics
Prof. Robert Oehmke, Ch.
March 30, 11:30 p.m., 101-J MLH

Macrofossil Distribution in the Stanton Limestone (Upper Pennsylvanian) in Eastern Kansas
Michael A. Senich, Geology
Prof. Philip Heckel, Ch.
April 1, 10:00 a.m., 20 TH

Joseph Joachim, Violinist, Pedagogue, and Composer
Barrett Stoll, Music
Prof. Eldon Obrecht, Ch.
April 2, 10:30 a.m., Music Library, 2000H MB

A Survey of Selected Iowa Principals' and Superintendents' Attitudes Towards and Knowledge of Programming for Handicapped Students in the Least Restrictive Environment
Peter Alan Kurzberg, Education
Prof. Willard Lane, Ch.
April 3, 8:00 a.m., 210A LCM

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SUBMAXIMAL EXERCISE TESTING

TREADMILL AND FLOOR

WALKING

by

William L. Rohrig

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Arts in Physical Therapy
in the Graduate College of
The University of Iowa

May, 1978

Thesis supervisor: Assistant Professor David H. Nielsen

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MASTER'S THESIS

This is to certify that the Master's thesis of

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has been approved by the Examining Committee for the thesis requirement for the Master of Arts degree in Physical Therapy at the May, 1978 graduation.

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AN ABSTRACT

Exercise testing has been used as the basis for exercise prescriptions for a variety of patients. Exercise tests are performed using standardized ergometers such as a treadmill, bicycle, or steps. There have been, however, several drawbacks to these ergometers which limit their clinical utility. Tests performed on the treadmill have been equated to floor walking, although this has not been conclusively proven. The purposes of this study, therefore, were to examine the validity of using level walking as a submaximal exercise test, and to compare the energy cost of level treadmill and floor walking.

Thirty male subjects walked over three modes of level walking: segmental, circular, and treadmill walking. Seven walking velocities were used on all modes; 26.82 to 107.29 meters per minute (1.0 to 4.0 miles per hour). A maximal exercise tolerance test was also performed to determine maximal aerobic power (MAP). Oxygen uptake and heart rate values were determined at each walking velocity for each mode. Multiple regression analysis of MAP versus the heart rates associated with the walking velocities demonstrated a reasonably accurate method of predicting MAP. Level walking, therefore, may have possibilities as a submaximal exercise test. Analysis of variance of the

linear regression of oxygen uptake versus the square of the walking velocity demonstrated similar slopes and intercepts for circular and treadmill walking, but a significant difference between these two modes and segmental walking. Level treadmill and circular walking appear similar in energy cost, but segmental walking, which requires more turns, may require greater oxygen uptake.

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This thesis is dedicated to Sherry, Scott, and Brent.

TABLE OF CONTENTS

CHAPTER		Page
V.	DISCUSSION OF THE RESULTS	66
	Oxygen Uptake and Heart Rate	67
	Predicting Energy Cost from Walking Velocity	69
	Maximal Aerobic Power Prediction	75
	Clinical Implications	80
VI.	SUMMARY AND CONCLUSION	82
	Purpose of the Study	82
	Procedures	82
	Summary of the Results	83
	Conclusions	84
	Recommendations for Further Study	85
APPENDIX A	SUBJECT INFORMATION SUMMARY AND CONSENT FORM	86
APPENDIX B	PHOTOGRAPH RELEASE FORM	89
APPENDIX C	MEDICAL HISTORY FORM	91
APPENDIX D	SPECIAL EQUIPMENT	95
APPENDIX E	CALIBRATION PROCEDURES	107
APPENDIX F	CALCULATOR PROGRAM	121
APPENDIX G	STANDARD TEMPERATURE AND PRESSURE, DRY CONVERSION FACTORS	125
APPENDIX H	SUBJECT AGE AND WEIGHT	127
APPENDIX I	INDIVIDUAL SIMPLE LINEAR REGRESSION ANALYSES	130
APPENDIX J	DATA WORK SHEETS	143
LIST OF REFERENCES	. . . .	146

LIST OF TABLES

Table		Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Background of the Study

Energy expenditure has been used to evaluate the stress an activity imposes upon the individual. The energy requirement has been shown to increase as the intensity of the activity increases, and has been established for many activities[16,27]. The effects of trauma and disease on functional activities, including walking, have been assessed in this manner. Energy cost of ambulation has been studied in patients who have had corrective surgery[30], in hemiplegics[4,11], paraplegics[9,19], amputees[4,17,35], and in patients with coronary heart disease[22,42], as well as in normal subjects[5,6,8,10,13,14,18,20,21,24-26,29,31,32,36,38-41]. The energy capabilities of an individual are important to know in order to provide adequate patient counseling and exercise training recommendations.

Accurate assessment of work capacity, expressed as aerobic power, and the associated heart rate with known work loads have been accomplished through graded exercise tests. The results of such tests are used as the basis for exercise prescription by providing objective criteria by which a proper exercise program may be carried out. Care must be

taken to prescribe exercise which is not too strenuous as to precipitate problems with the cardiopulmonary or musculoskeletal systems, but strenuous enough to elicit an adequate training response. The desirable exercise intensity is usually achieved by working at an appropriate percentage of the maximum work capacity as reflected by a certain percentage of the maximum heart rate achieved, or predicted, from a graded exercise test. The graded exercise test may also be used at later dates to assess training adaptations.

Standardized procedures and comparisons of the exercise tests conducted on the stepping, bicycle, and treadmill ergometers are available[6,21,26,40]. While valid and precise results are obtained from these testing regimens, certain disadvantages have minimized their use in many clinics.

The methodology behind the treadmill ergometer, i.e. walking or jogging, is commom to all subjects and the treadmill is effective in providing well defined results, however, size and cost are often prohibitive to crowded hospital departments with limited clinical budgets. Noise is an added disadvantage. The bicycle ergometer has been used extensively in Europe and America. The ergometer is braked electrically or mechanically and can be dependent or independent of pedaling speed. The price of equipment is again high, but not as costly as the treadmill. However, undue leg fatigue in subjects who are unaccustomed to such work is a limiting factor and disadvantage. The step

ergometer is the least expensive form of exercise testing apparatus, but for many orthopedically handicapped patients this mode of activity is prohibitive. Also, individuals who are not accustomed to climbing stairs or using their legs to any extent, may experience undue muscle strain and soreness similar to the problems encountered in using the bicycle ergometer. To insure accuracy of the step ergometer it is important to maintain a specific cadence by keeping time with a metronome. For many this is difficult to accurately achieve, especially for the neurologically impaired patient.

Varying amounts of technical skill are also required for each of these ergometers. These factors limit universal acceptance and clinical application. A simple method of evaluating an individual's work capacity without the use of expensive equipment or the need for exceptional technical skill would have clinical utility. The necessity for a simplified test has been recognized and described in the literature[5,39,40].

Level floor walking at increasing velocities could be used as a submaximal exercise tolerance test. This has been reported as a favorable approach[5]. Comparisons have been made between various ergometers and continuous overground walking[14,22,31,40,41].

Studies concerned with level floor walking have been conducted over rectangular or oval courses to maintain a

continuous pace[5,6,10,20,22,31,32]. While this approach is conducive to measurement of physiological parameters and the attainment of steady state conditions, most clinics do not have access to this type of continuous walking facility. Corcoran and Brengelmann[10] utilized a four hundred foot course in a long hallway which simulated reasonably well the clinical situation. No reference, however, was made to how their subjects negotiated this course, especially with respect to stopping or turning.

Walking back and forth, segmentally, in a clinic gymnasium or hallway is an alternative method which should be available to all clinical settings has received little consideration. Two basic factors need to be investigated concerning whether or not steady state conditions can be achieved during segmental walking and whether or not differences in energy cost between segmental and continuous walking exist before this approach can be adopted. Since considerable data has been collected on the treadmill, an additional consideration is whether or not differences exist between the energy cost of floor versus treadmill walking. The present literature does not provide adequate information.

Statement of the Problem

The purposes of this study were to investigate the use of level walking including back and forth, segmental,

walking as a submaximal exercise tolerance test and to clarify whether or not differences in energy cost exist between treadmill and floor walking.

In presenting this study it was found that the purposes could best be achieved by considering and answering the following related questions:

1. How well can maximal aerobic power (MAP) be predicted from submaximal walking tests?
2. Are there differences in heart rate and oxygen uptake responses to back and forth, segmental, continuous circular, and treadmill walking?
3. Can steady state conditions be achieved during back and forth, segmental, walking?
4. How well can energy cost be predicted from walking velocity?

Scope of the Study

Thirty normal male subjects participated in the study. Each subject walked at three modes of level walking. Seven walking velocities were used and were consistent for each of the three modes. Each subject, also, participated in a maximal treadmill exercise test to determine maximal aerobic power. Oxygen uptake and heart rate data were determined for all velocities for each mode of walking.

Differences in energy costs were assessed by analyzing the slopes and intercepts of regression lines. The first

regression analysis considered oxygen uptake versus the square of the walking velocity and the second regression analysis, oxygen uptake versus heart rate. In addition, differences in oxygen uptake were analyzed between each of the three modes of walking according to walking velocity. MAP was predicted from each of the three walking modes, and an analysis of variance was used to test the differences between predicted MAP and MAP determined from the maximal treadmill test. Multiple regression equations were generated to predict MAP from heart rate data for different walking velocities.

Significance of the Study

This study provided insight into a simple procedure of applying exercise testing objectives in a clinical setting without the necessity of elaborate equipment. Insight was gained concerning the question of whether or not differences in energy cost exist between treadmill and floor walking.

Limitations of the Study

The study was conducted on normal subjects. Extrapolation of information to patient populations with ambulatory problems such as the neurologically or orthopedically involved individuals would require additional investigation. The results of this study may not be immediately applicable to a clinical setting, but would be a meaningful and necessary step in a thorough investigation of the problem.

Definition of Terms

Energy cost. The metabolic requirement of physical activity is reflected by steady state oxygen uptake ($\dot{V}O_2$). For this study it was normalized to body weight and expressed in terms of milliliters of oxygen consumed per kilogram of body weight per minute (ml O_2/kg-min)[3].

Maximal aerobic power (MAP). Maximal aerobic power is the maximal oxygen uptake an individual is capable of obtaining[3,27], and is expressed in milliliters of oxygen consumed per kilogram of body weight per minute.

Steady state. The condition in which the oxygen supplied by the cardiorespiratory system is equal to the metabolic demands for a given work level[3]. The linear relationship between heart rate and oxygen uptake justifies the use of heart rate as an index of steady state conditions.

Segmental walking. Segmental walking refers to a method of walking back and forth along a straight walkway of known length. It requires that the walking subject turn in some pivot-like manner rather than continue walking around a curve as on an oval or circular track.

CHAPTER II

REVIEW OF LITERATURE

The purpose of this chapter is to provide additional background information related to the stated problems of this study. The review of the literature has been divided into the following topics: Progressive exercise tests; energy cost of level walking; level walking as a submaximal exercise test; and steady state requirements.

Progressive Exercise Tests

Graded exercise tests are often accomplished to evaluate responses to training and/or preventative programs and to increase individual motivation and adherance to exercise programs[1,27]. In this context total body energy cost has been used as a direct index of exercise intensity for the determination of aerobic power. Aerobic power can be expressed in terms of kilocalories per minute, total oxygen uptake per minute ($\dot{V}O_2$), or as metabolic equivalents (METs)[1,3,27].

It is generally accepted that energy requirements are best obtained from these tests by utilizing large, antigravity muscle groups while performing rhythmical, dynamic exercise. The specific type of exercise performed depends upon the ergometer used. The duration of the exercise

depends on the test protocol; whether it is a maximal or submaximal design.

The graded exercise test is characterized by starting the subject at a low intensity workload and systematically increasing the exercise intensity. The subject's physiological parameters of heart rate, blood pressure, respiration, expired air, ECG, and central nervous system signs of incoordination and incoherence are often monitored during the progression of the test. In a maximal test the workload is increased until there is no further increase in oxygen consumption. When this plateau is reached the test is terminated.

The main advantage of performing the maximum test is that a definite maximum aerobic capacity can be arrived at without calculation. Also, the heart rate corresponding to the maximum aerobic capacity can be more accurately noted.

A test may also be a symptom limited maximum in which the progression is terminated by signs of exercise intolerance regardless of whether the oxygen consumption has plateaued. Included in these signs would be ECG S-T segment depressions or arrhythmias, abnormal response of heart rate or blood pressure, or incoordination and incoherence.

The hallmark of a submaximal exercise test is having an arbitrary stopping point established before the test

begins. The termination point is indicated when the subject's heart rate reaches a percentage of the age predicted maximum, usually in the range of eighty to ninety percent. Heart rate has been shown to increase with increased exercise intensity and has been demonstrated to be a valid index of energy cost[5,8,12,13,16,17,42]. Maximum aerobic power may be obtained by extrapolating out to the age predicted maximum heart rate when plotted against oxygen consumption.

When using age predicted maximum heart rate to predict maximum oxygen uptake, it must be noted that the maximum heart rate decreases with age. The maximum heart rate may be estimated by utilizing the charted values given by Sheffield[34] or the formula presented by Fox[16], maximum heart rate equals the difference between 220 and the individual's age (max HR = 220 - age). Fox noted that this estimation may be somewhat lower than the actual decline with age, but it should have little effect on the exercise prescription.

Energy Cost of Level Walking

The energy requirements of level walking have been the subject of a variety of studies. The effects of velocity have been well documented[6-8,10,14,17,18,20,21,22,24,25,31,32,36,38,41]. Generally speaking these investigations have demonstrated that the energy cost increases

as the velocity increases. The precise relationship is a parabolic curve when energy cost is plotted against velocity. However, when plotted as the second order, with the velocity squared, the relationship becomes linear[6,8,10,25,32,41]. This comparison is evident regardless of the type of surface the subject walks over. Investigations performed on a treadmill[7,8,14,18,21,22,25,29,31,36,38-41], a continuous track[6,32], the floor[5,10,20,22,31], and on a roadway[14,41] demonstrate similar patterns.

In 1953, Daniels, Vanderbie, and Winsmann[14] reported a comparison of treadmill, road, and cinder track walking. The environmental and experimental conditions were not constant since the treadmill tests were performed inside and the road and track tests were taken outside at different temperatures. The subjects wore 46 pound packs for the roadway comparisons to treadmill walking, and eight pound armor vests during the track to treadmill comparisons. In addition, the subjects wore fatigue uniforms, including combat boots. This study demonstrated a nine to ten percent increase in energy cost of the track and roadway walking when compared to treadmill walking at similar speeds.

A factor influencing the energy cost of walking is the apparel, especially the type of shoes that the subject is wearing[15]. Heel height is of importance as it has been demonstrated that three inch high heels can cause an increase of 10 to 15 percent in energy cost. Also, an additional

two and one-half pounds of shoe weight can increase energy cost five to ten percent[15]. This may be an influencing factor in the results noted in the Daniels et al[14] study.

In a better controlled study, Ralston[31] standardized the apparel of his subjects and tested them over the floor and on a treadmill, at two velocities. The complete data was not presented, as the results for only one of the velocities were listed. It was explained that the data for the other were similar and, therefore, unnecessary to include. It was concluded that there was no significant difference between the two modes of walking.

Wyndham, Strydom, van Graan, van Rensburg, Rogers, Greyson, and van der Walt[39] conducted a study in 1971 which was primarily concerned with the effects of weight on the energy requirements of level walking. While citing the conflicting results of the two previous studies, they also compared level treadmill and floor walking in an attempt to resolve this controversy. Although the treadmill was not described in detail, the road on which the walking was performed was described as a flat, tar-macadam composition. The subjects were measured over three walking velocities. No comments were offered on the subjects attire during the tests or the experimental conditions under which they were held. The results failed to highlight conclusive evidence in favor of either of the previous two studies. The oxygen consumption for road walking was significantly higher than

the treadmill for the two lower speeds, but not at the higher speed, 6.4 kilometers per hour. While this agreed with Ralston's results at a similar velocity, it disagreed with the Daniels et al[14] study. Wyndham's[39] own conclusion was that this question remains open to further investigation.

In summary, it may be said that there is a direct relation between energy cost and velocity of walking. This is a linear relationship if energy cost is plotted against the squared velocity. However, direct comparisons between level floor walking or roadway walking to treadmill values remains a question.

Level Walking as a Submaximal Exercise Test

In 1976, Bassey, Fentem, MacDonald, and Scriven proposed level walking as a form of exercise testing[5]. The advantages of this method were outlined as being more acceptable to the elderly, orthopedically involved individual, a familiar form of exercise which does not require training, and a test which is sensitive to age differences. Furthermore, it was felt that this method was more relevant to the demands of daily living and a realistic method for longitudinal studies. Conventional tests were not found to be satisfactory by the authors as they felt the measurements were biased because the fittest subjects were often selected. The general requirements for a valid exercise test, that the subjects perform rhythmic exercise with large muscle groups

over several work levels, are met by this method. Reproducibility is also an important criteria which was demonstrated to be present in this procedure.

Thirty-four subjects were asked to walk at three self-paced speeds over a rectangular course. Actual velocities were then calculated from time and distance factors at the completion of the trials. Heart rate was the only physiological parameter measured, and this was found to reach steady state on the second lap of the course. These results were then compared to those obtained from a progressive exercise test performed on a bicycle ergometer. There was a significant correlation between walking heart rate and oxygen uptake associated with equivalent heart rates determined from the bicycle test (correlation coefficient, $r = 0.79$, $P > 0.001$). No attempt was made to predict work capacity nor were any comparisons made with treadmill walking.

Steady State Requirements

Steady state is an important consideration in exercise testing. In order to obtain an accurate assessment of the body's energy demands, samples of metabolic parameters must reflect the true metabolic needs at that moment in time. This is what is accomplished by measuring the physiological data during that period when the energy costs of the body are being equalized by what the cardiorespiratory system provides. This period of balance between energy demands and

energy supplied is the steady state condition. This has been demonstrated with treadmill and continuous floor walking[4-7,13,26]. Bassey et al[5] felt they had achieved this even at their low work intensities. Previous studies[5,6,10,20,22,31] which were concerned with continuous walking did not assess whether or not physiological steady state could be maintained when turning around was required.

CHAPTER III

PROCEDURE FOR OBTAINING DATA

The procedures involved in conducting the study will be outlined in this chapter. A description of the subjects, the experimental design, test facilities and equipment, the method, the procedures for data reduction, and the method of statistical analysis are presented.

Subjects

Thirty normal, young adult males were employed as subjects for the study. A summary of the purpose and procedure to be used in the study was explained to each subject prior to their signing a subject consent form, presented in Appendix A, page 88, and photograph release form, presented in Appendix B, page 90. A medical history form was completed by each subject. An example of this form is presented in Appendix C, pages 92 to 94. A cardiologist confirmed from these histories that all subjects were healthy and would be able to complete the study.

Experimental Design

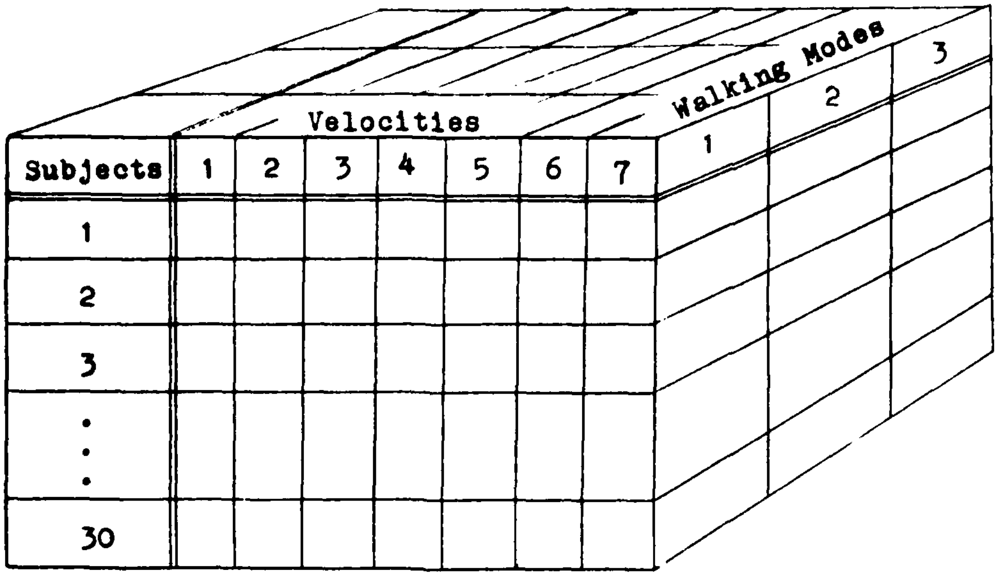
The study was based on a treatment by treatment by subjects design in which all treatments were administered to the same subjects[23]. One treatment consisted of the

following seven walking velocities: 26.82, 40.23, 53.64, 67.06, 80.47, 93.88, and 107.29 meters per minute. (This corresponds to 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0 miles per hour, respectively.) The second treatment consisted of three modes of level walking (segmental or back and forth, continuous circular, and treadmill). The design is schematically illustrated in Figure 1, page 18. In addition to this a maximal treadmill exercise test was administered to each of the subjects.

Test Facilities and Equipment

The facilities utilized for conducting this study included a general research laboratory and a hospital auditorium in which a segmental walkway and a circular walking course were located, respectively. The equipment and instrumentation used for this study consisted of a speed control tracking system, a speedometer cane, a treadmill, electrocardiograph equipment, oxygen uptake equipment, and a programable calculator.

Walkways. The segmental walkway was located in the general research laboratory. The walkway is photographically presented in Figure 2, page 19. The laboratory walls bordered the walkway on each end and along one side. The fourth side was open to the laboratory. The walkway was 13.4 meters long and 1.5 meters wide. The walking surface was a level, tiled floor. Walking velocity was regulated with an overhead speed control-tracking system.



Velocities (m/min)

1 = 26.82
2 = 40.23
3 = 53.64
4 = 67.06
5 = 80.47
6 = 93.88
7 = 107.29

Walking Modes

1 = Segmental
2 = Circular
3 = Treadmill

Figure 1

Schematic Illustration of
Experimental Design

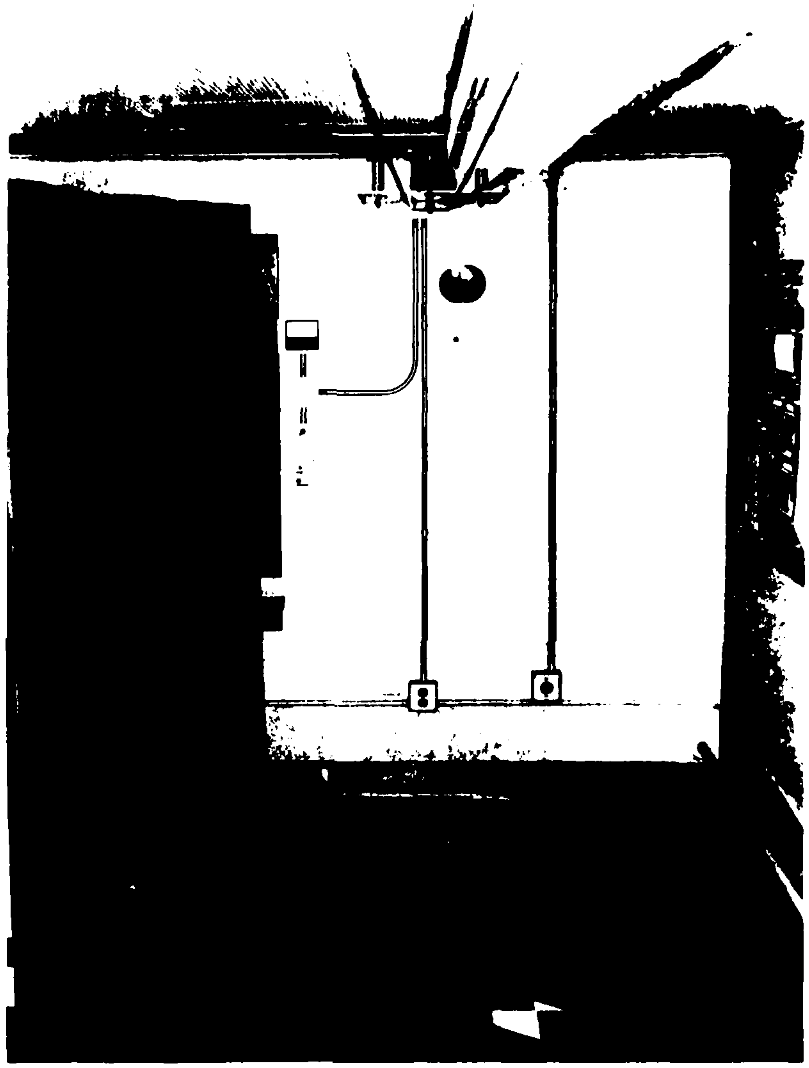


Figure 2

Segmental Walkway

The circular walking course was located in an open hospital auditorium. The auditorium is pictured in Figure 3, page 21. An 18.4 meter diameter circle was marked off with tape on the auditorium floor. The walking surface was a level, tiled floor similar to the segmental walkway. Walking velocity was regulated with a speedometer cane specifically designed for this study.

<u>Speed control-tracking system</u>. An overhead speed control-tracking system was developed to regulate walking velocity on the segmental walkway. A detailed description is included in Appendix D, page 96. The system consisted of a continuous urethane plastic chain stretched in a horizontal loop over the entire length of the walkway. The chain was supported at either end by metal gear sprockets. A rubber, foam ball was attached to the chain which the subject followed as he walked along the walkway. The power for turning the system was provided by a direct current electric motor connected via a transmission gear box to one of the sprockets. The electric motor was controlled by a SCR motor control package, which varied the amount of current to the motor. A meter was incorporated into the circuit and was calibrated according to the velocity of the chain in centimeters per second. A description of the calibration procedures is included in Appendix E, page 108. The functional range of the system was 17 to 225 centimeters per second.

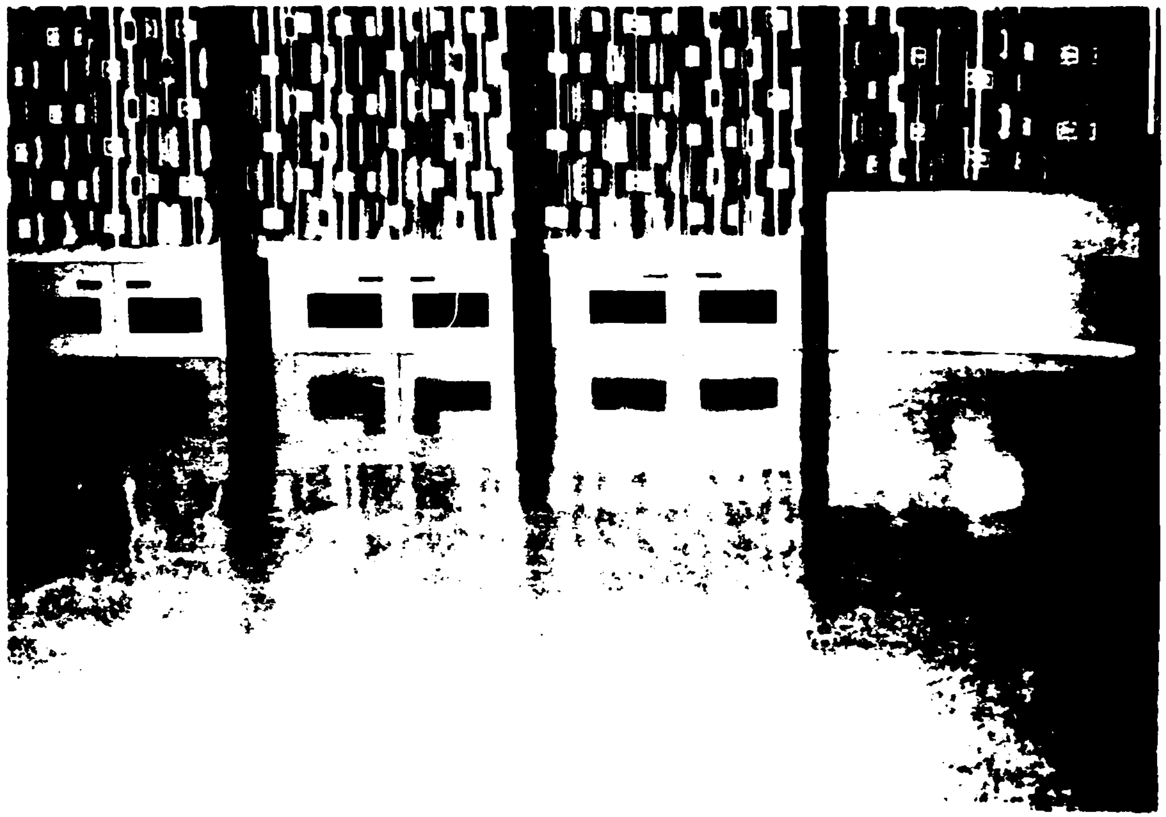


Figure 3

Auditorium for Circular
Walking Course

Speedometer cane. Walking velocity on the circular course was controlled with a speedometer cane which the investigator or an assistant held as he walked with the subject. The cane is photographically presented in Figure 4, page 23. A detailed description is presented in Appendix D, page 99. The cane was instrumented with a revolving wheel at the tip end and an electronic revolution counter on the shaft adjacent to the handle and was calibrated in centimeters per second. The calibration procedures are described in Appendix E, page 110.

Treadmill. A Quinton[a] model 18-54 motor driven treadmill with variable speed and grade capabilities was used for level walking and for the maximal exercise test. The treadmill is pictured in Figure 5, page 24. The speed and grade ranges were 0 to 10 miles per hour and 0 to 27 percent, respectively, and were calibrated accordingly. See Appendix E, page 112 for a description of the calibration procedures.

Electrocardiograph equipment. A radio telemetry system was used to monitor heart rate. The system consisted of a model 1500B Hewlett Packard[b] electrocardiograph, a model 78101A Hewlett Packard FM receiver, and a nine volt battery operated Hewlett Packard model 78100A transmitter. The FM receiver was connected directly to the electrocardiograph.

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[a] Quinton Instruments, Seattle, Washington 98199

[b] Hewlett Packard, Cupertino, California 95014

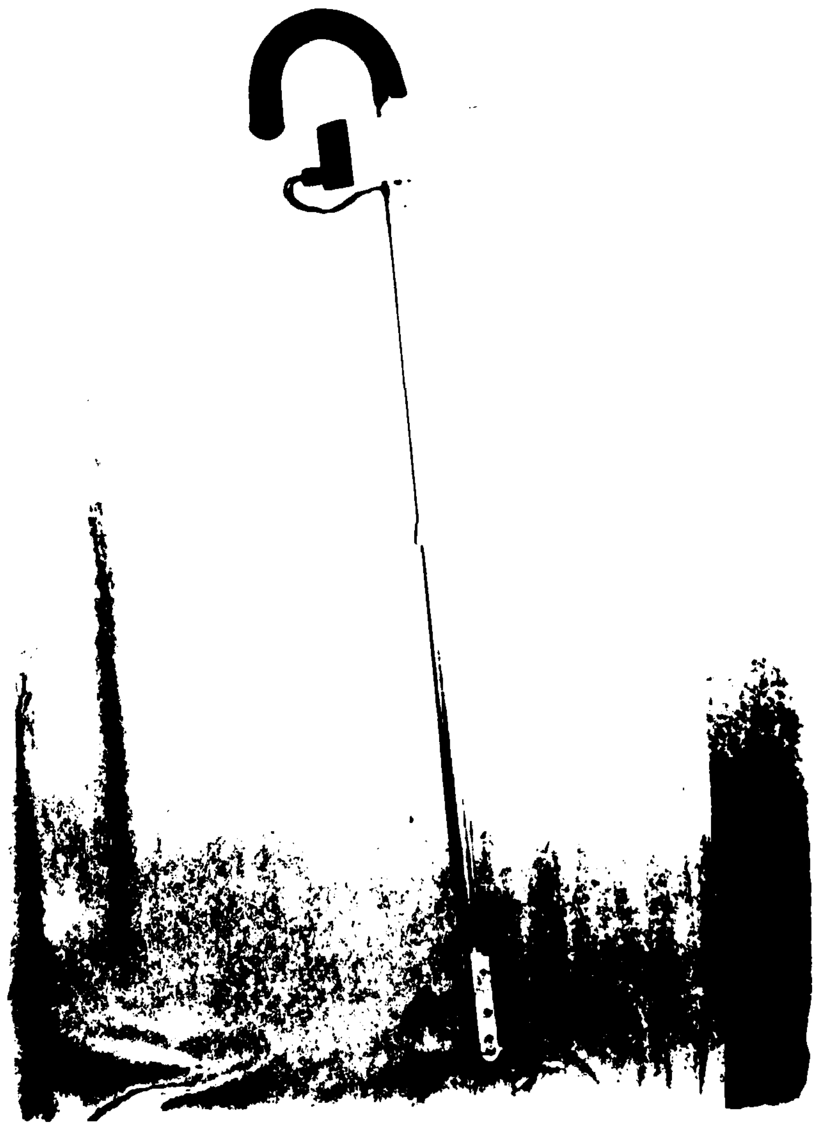

Figure 4

Speedometer Cane

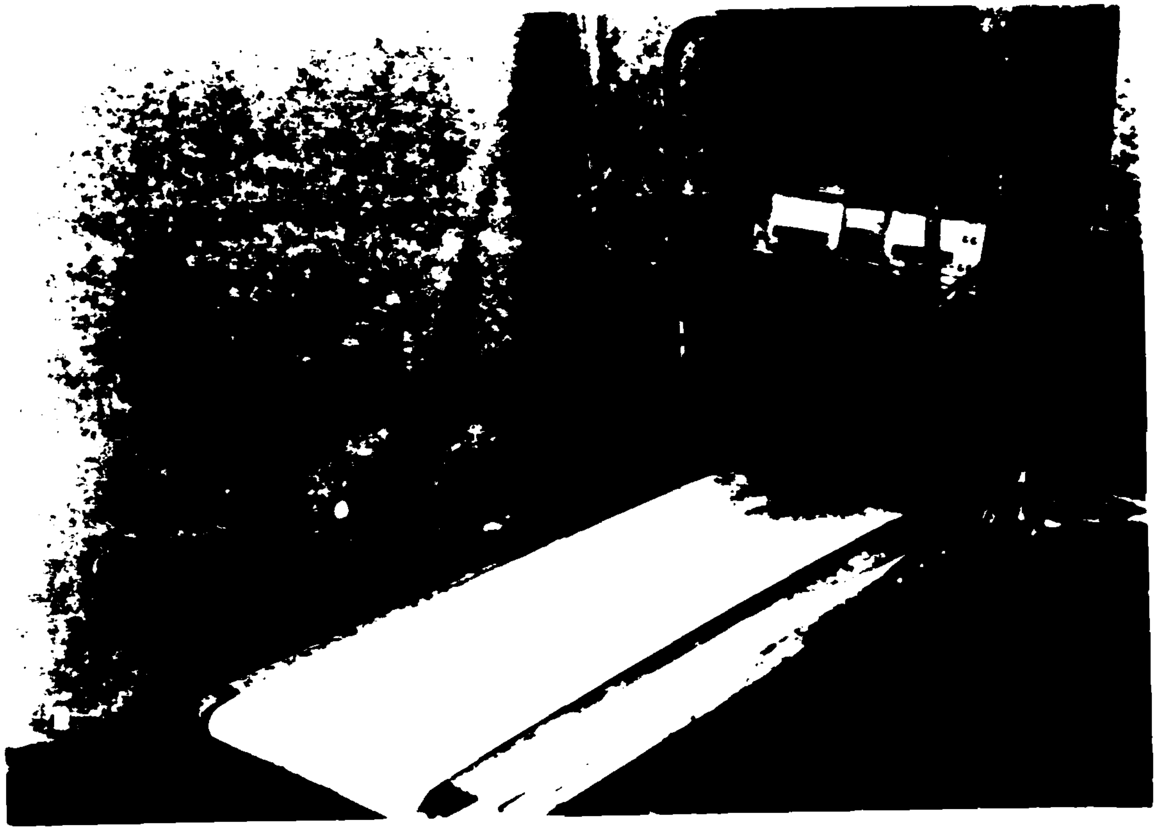

Figure 5

Quinton Treadmill

The transmitter was placed in a cloth pouch which was attached to a cloth belt that was worn around the waist of the subject. Through experience it was found that the best location for the pouch and transmitter was over the sacral area of the back. This minimized movement of the transmitter and in no way interfered with the exercise of the subject. A Hewlett Packard three lead exercise cable with reusable electrodes, model 14120A, and disposable electrode adhesive discs, model 14095B, were used. The telemetry and electrocardiograph equipment is presented in Figure 6, page 26. The manufacturers recommended standard lead electrode placement was found to be optimal for the present application.

Oxygen uptake equipment. An open circuit method was employed to determine the oxygen uptake. The equipment consisted of (1) a rubber mouth piece, (2) two types of respiratory valves, (3) a nose clip, (4) a flexible tube, (5) a plastic head harness, (6) Douglas Bags, (7) gas analyzers, (8) a dry gas meter, (9) a mercury barometer, and (10) a centigrade thermometer.

One respiratory valve was the Collins[a] plastic two way J-valve. This valve was used during rest and during moderate exercise, as in the walking tests. During the exercise test, when deeper and more rapid breathing

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[a] Warren E. Collins, Inc., Braintree, Massachusetts 02184

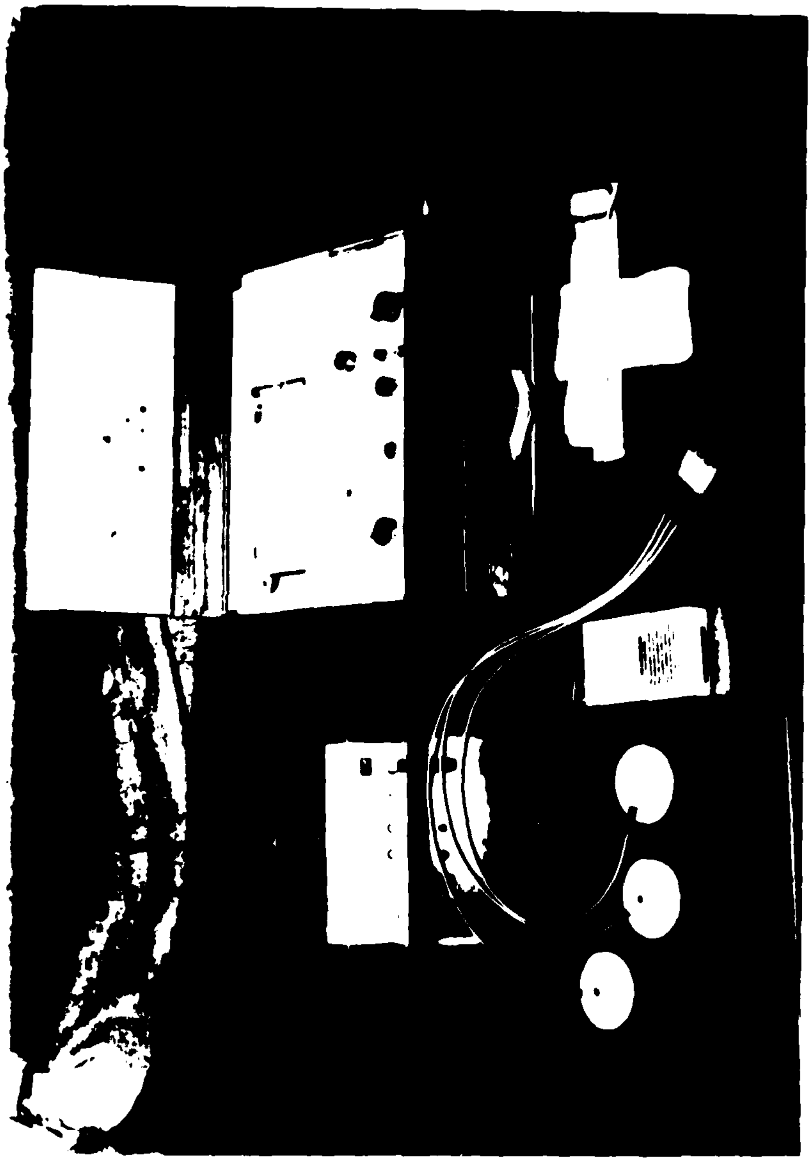

Figure 6

Telemetry and Electrocardiograph Equipment

patterns were encountered, the Collins triple J-valve was used to insure minimal airway resistance. The valves were supported by the rubber mouth pieces held in the subject's mouth and the plastic head harness. The head harness was adjustable in circumference and length. The J-valves allowed inspiration of room air while directing the expired air to the collection bags via the flexible tubing. The tubing was 3.2 centimeters in diameter and 1.2 meters in length. The J-valves, rubber mouth pieces, and a nose clip are shown in Figure 7, page 28. The head harness with the two way J-valve is shown in Figure 8, page 29.

Plastic 60 and 100 liter Douglas Bags, Collins models 22619 and 22621, respectively, were used in the study. Each bag was fitted with a Collins T-shape stopcock valve, model 21043, to control the opening and air collection. This valve contained a gas inlet port for returning the expired air to the bag after sampling. The bag itself had a built-in sampling tube from which air samples were drawn. These sampling tubes were closed with spring clamps during air collection. An example of the Douglas Bag with stopcock valve attached is presented in Figure 9, page 30.

Beckman[a] electonic gas analyzers, model OM-11 paramagnetic oxygen (O_2) gas analyzer and the model LB-2 infrared carbon dioxide (CO_2) gas analyzer, were used to

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[a] Beckman Instruments, Inc., Schiller Park, Illinois 60176

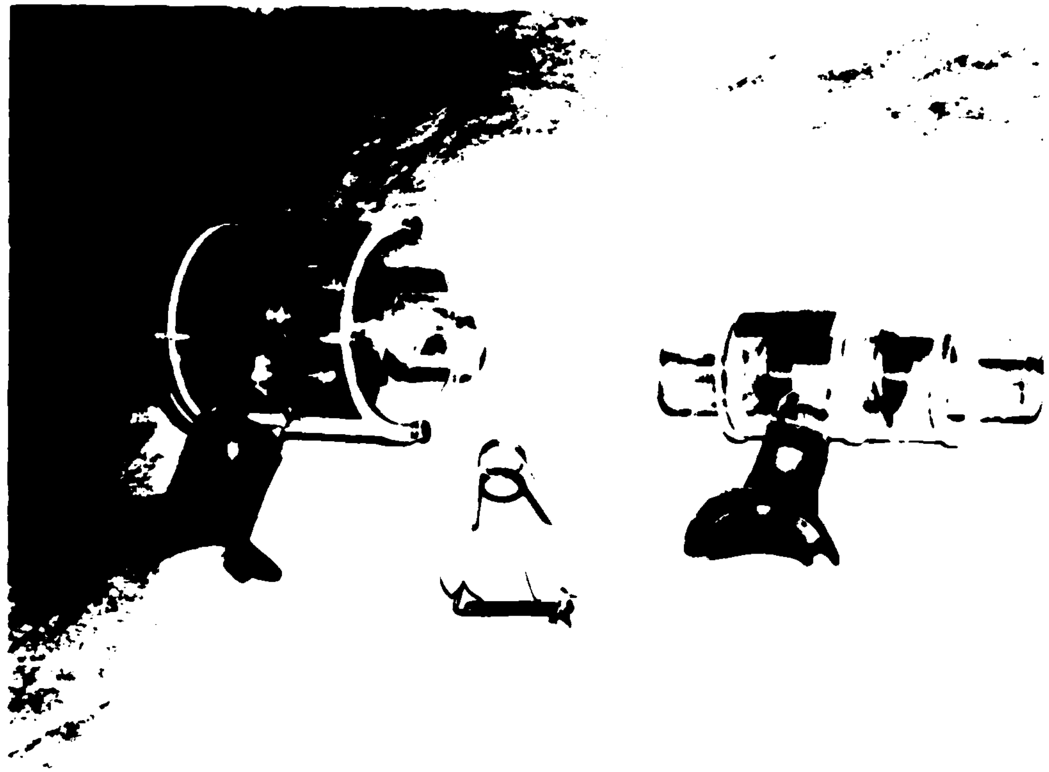

Figure 7

Triple and Two Way J-valves with Mouth Pieces and Nose Clips

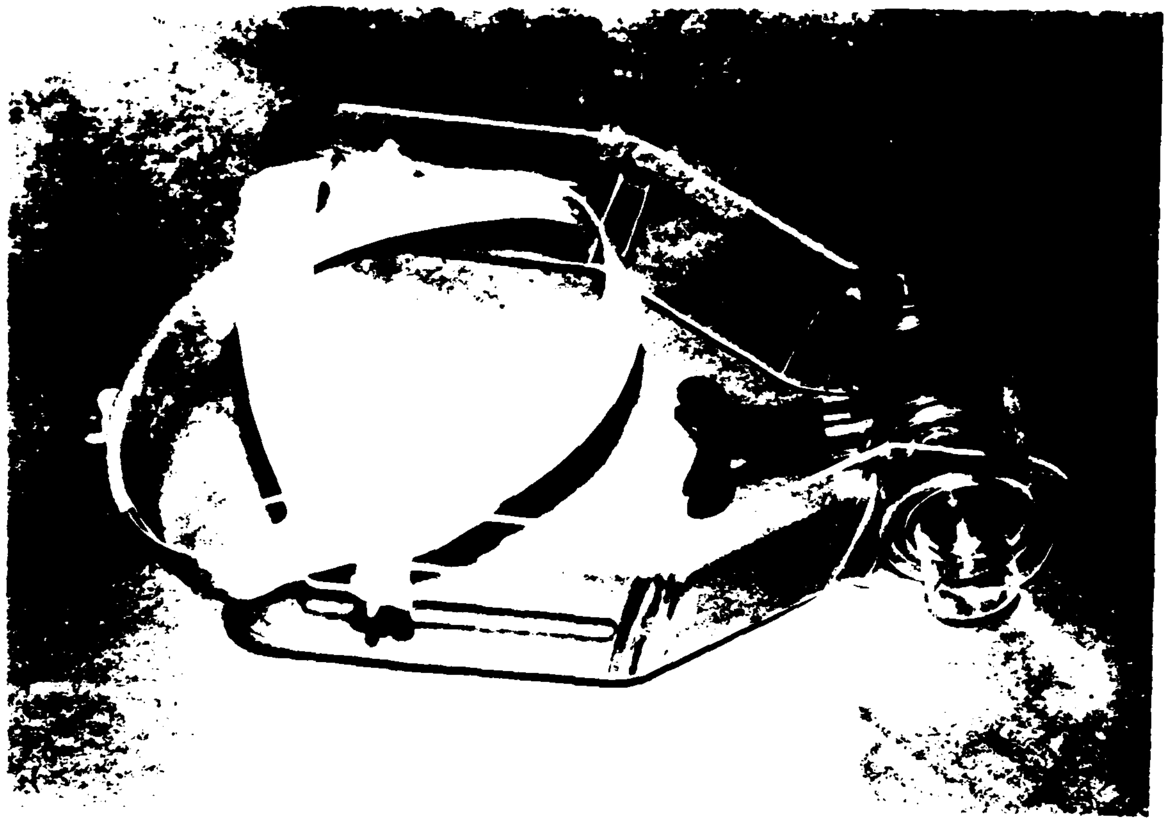

Figure 8

Plastic Head Harness with Two Way
J-valve and Mouth Piece

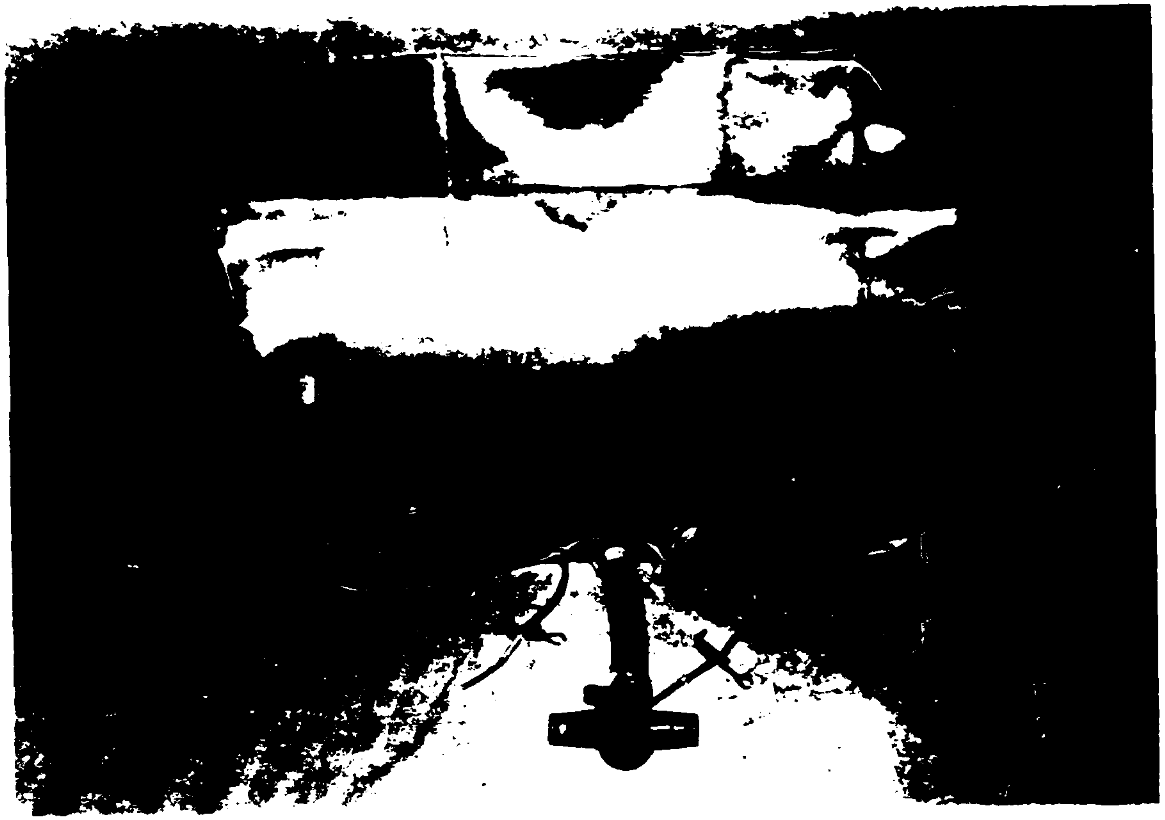

Figure 9

Douglas Bag with T-shape
Stopcock Valve

determine the O_2 and CO_2 concentrations in the collected expired air. Each analyzer consisted of two units, a remote pick-up head and a central unit containing a suction pump for drawing the gas samples, and a digital meter which displayed the gas concentrations in percent values. The accuracy of the O_2 analyzer was 0.1%. The accuracy of the CO_2 analyzer was 0.01%. Both analyzers were calibrated with known gases prior to the testing of each subject. Details of this calibration are outlined in Appendix E, page 118. The Beckman O_2 and CO_2 analyzers are presented in Figure 10, page 32.

Small diameter tygon tubing was used to connect the Douglas Bag sampling tube to the O_2 pick-up head which was connected in series to the CO_2 pick-up head and the suction pump of the central unit of the O_2 gas analyzer. The same type of tubing was used to connect the exhaust port of the suction pump to the gas inlet port of the stopcock valve connected to the Douglas Bag. This arrangement required the use of only one suction pump and flow meter, which was manually set at 500 cubic centimeters per minute. It also allowed for the same gas sample to be analyzed for both O_2 and CO_2 concentrations and returned to the Douglas Bag. In this way the volume of the gas in the Douglas Bag did not change during the sampling. A photograph of the gas analysis system is presented in Figure 11, page 33.

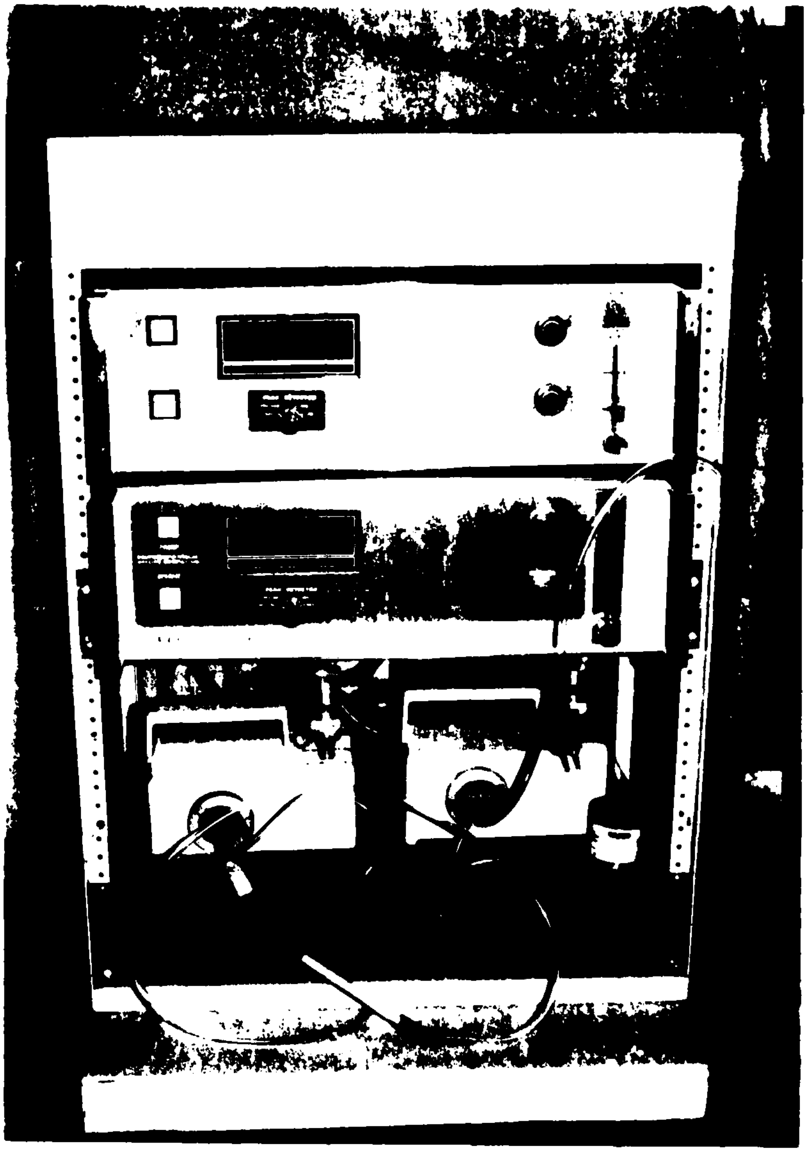

Figure 10

Beckman Oxygen and Carbon Dioxide Gas Analyzers

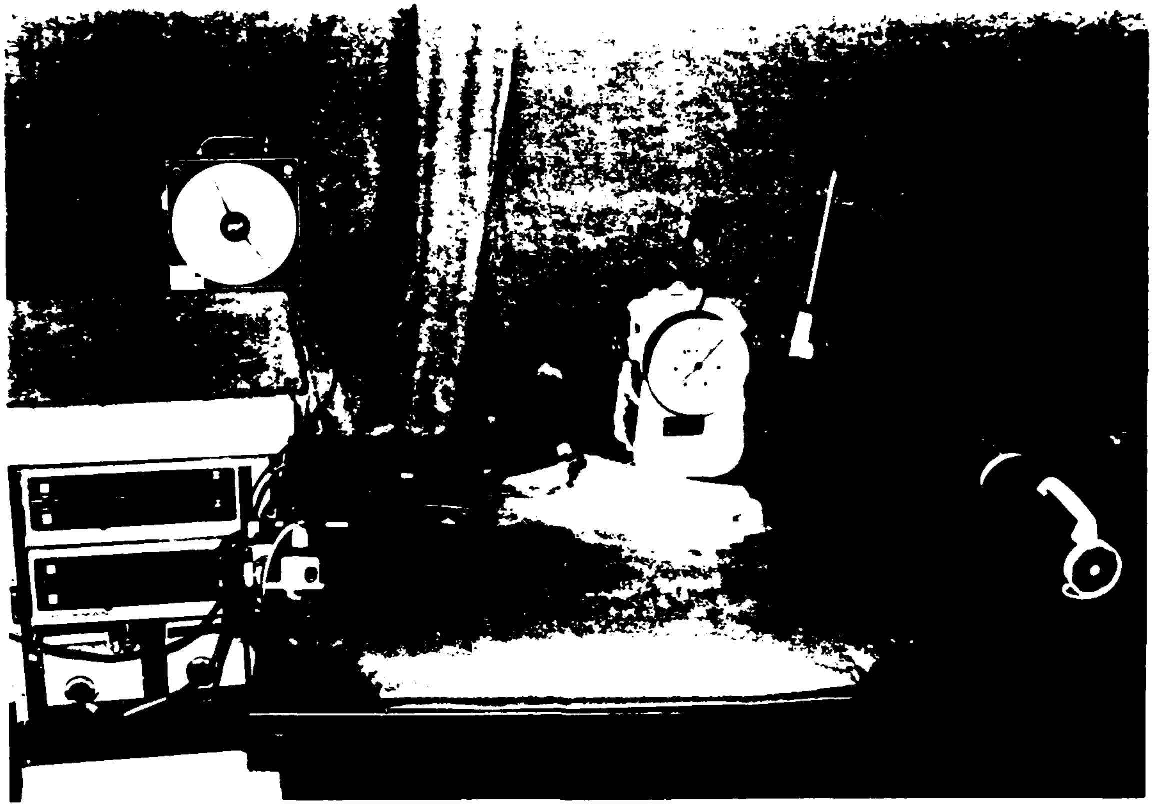

Figure 11

Expired Gas Analysis System

An American Meter Company[a] model DTM-115 dry gas meter was used to determine the volume of expired air. This meter is presented in Figure 12, page 35. The collected air sample was drawn through the gas meter at a uniform flow rate by a Sears[b] portable vacuum cleaner, model 208.6150. The volume obtained was read in liters indicated by a series of dials on the face of the meter. The meter was accurate to 0.01 liters. A correction factor was applied to this volume measurement based on instrument calibrations as outlined in Appendix E, page 118.

The mercury barometer was used to measure atmospheric pressure. This reading was compared with the barometric pressure of the city airport. The centigrade thermometer was used to record the room temperature and the temperature of the expired air samples. The barometric pressure and gas sample temperatures were necessary in the calculations of oxygen uptake. The room temperature values were used to help standardize environmental conditions. The barometer is presented in Figure 13, page 36.

The oxygen uptake calculations were performed on a Hewlett Packard model 97 programable, printing calculator. A photograph of the calculator is presented in Figure 14, page 37. The oxygen uptake values were printed by the

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[a] Warren E. Collins, Inc., Braintree, Massachusetts 02184

[b] Sears Roebuck and Co., Iowa City, Iowa 52240

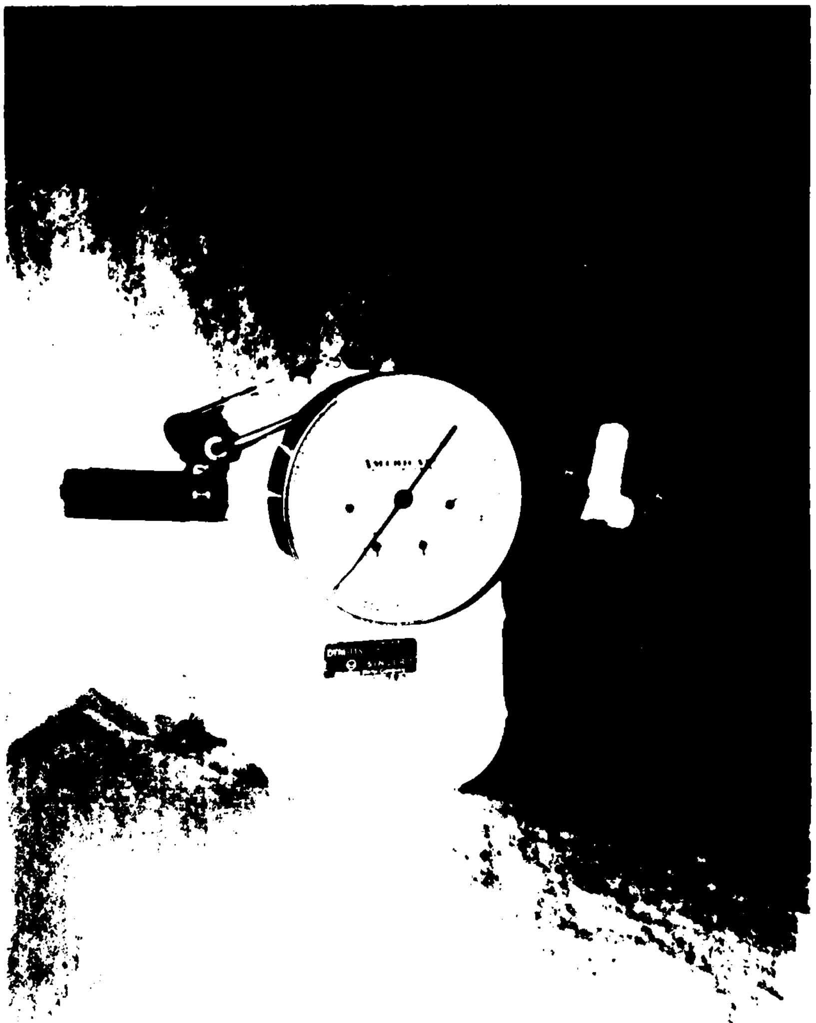

Figure 12

Dry Gas Meter with Thermometer

Figure 13

Mercury Barometer

Figure 14

Hewlett Packard Model 97 Calculator

calculator on heat sensitive paper. The program utilized in these calculations was written by the investigator and is included in Appendix F, page 124. The program was transcribed to magnetic tape for easy accessibility and storage.

A standard laboratory electric timer, with a minute and a sweep second hand, was used to monitor the time parameters during the testing procedures.

Method

The specific procedures followed in this study were concerned with the three modes of level walking, the treadmill exercise test, heart rate, and oxygen uptake measurements.

Level walking. The subjects were weighed prior to each level walking trial. Similar loose fitting clothing and rubber soled shoes were worn for each trial. The subjects walked for five minutes at each of the seven velocities (26.82, 40.23, 53.64, 67.06, 80.47, 93.88, and 107.29 meters per minute) for each of the three modes of level walking (segmental, circular, and treadmill). A one minute pause was included between velocities to allow the investigator to make appropriate technical adjustments.

Treadmill exercise test. The subjects' attire was similar to that used during level walking. The subjects were weighed before the exercise test. A modified Balke protocol[26] was used for the exercise test. The velocity of

the treadmill was maintained at 91.20 or 99.24 meters per minute (3.4 or 3.7 miles per hour, respectively) depending on the subject's capabilities. The workloads were systematically progressed by increasing the incline of the treadmill. The subject walked for five minutes at each workload with a one minute pause between workloads. The workloads were selected according to the subjects predicted maximal aerobic power obtained from the regression equation of oxygen uptake versus heart rate for segmental walking. A minimum of three workloads were used. The end point for the test was either a plateau of oxygen uptake or subject exhaustion.

Heart rate measurement. The standard lead electrode placement recommended by the manufacturer was adopted. This was a three electrode system similar to a modified CM_5 configuration. The electrodes were positioned as follows:

1. the right arm lead was placed at the mid-clavicular line just inferior to the right clavicle;
2. the right leg (ground) lead was placed at the mid-clavicular line just inferior to the left clavicle;
3. the left arm lead was placed in the V_5 position.

These positions resulted in a good quality ECG with minimal artifact. The electrodes were applied to these sites

after cleaning with alcohol and abrading the skin slightly to reduce the electrical resistance. The electrode cables were attached to the telemetry transmitter which the subject wore near the sacral area of his back with the support of the waist belt. Heart rate was monitored during the last ten seconds of each minute of exercise. The fifth minute recordings were considered to be steady state measurements and were used in subsequent data analysis.

Oxygen uptake measurement. Oxygen uptake was determined by the open circuit method. The plastic head harness was adjusted to fit each subject and was used to support the J-valve. Flexible tubing connected the J-valve to the Douglas Bag. The Douglas Bag was carried by the investigator or by an assistant during walking on the segmental walkway and on the circular course and was supported on an adjustable stand during treadmill walking. Examples of the procedures for segmental, circular, and treadmill walking are presented in Figures 15-17, pages 41-43, respectively. Expired air was collected during the last minute of each exercise trial. An exchange of Douglas Bags, an empty bag for the filled bag, and other appropriate technical adjustments were made during the one minute pause between exercise trials. The O_2 and CO_2 gas analysis were performed immediately on the precalibrated analyzers. The sampling tubes from the Douglas Bag and stopcock valve were connected to the inlet and exhaust tubes from the gas analyzers. The clamps were

Figure 15

Procedure for Data Collection on
the Segmental Walkway

Figure 16

Procedure for Data Collection on the Circular Course

Figure 17

Procedure for Data Collection
on the Treadmill

removed from the sampling tubes and the suction pump was turned on as was previously described in the oxygen uptake equipment section, page 31. The percentages of expired O_2 and CO_2 were read directly from the gas analyzers. Volume measurements were taken following the gas analysis. The sample tubes were reclamped and disconnected. The stop-cock valve on the Douglas Bag was connected to the inlet side of the dry gas meter and the air was drawn through the meter by the vacuum cleaner pump. The difference between initial and final meter readings was recorded as the uncorrected volume of expired air. Temperature was determined during this period to the nearest one half degree centigrade from the thermometer inserted in the exhaust tube of the dry gas meter. Atmospheric pressure was measured to the nearest millimeter from the mercury barometer.

A standardized procedure was followed in cleaning and sterilizing the mouth pieces and J-valves used in the procedure for expired air collection. The mouthpiece and J-valve were first rinsed in warm, running tap water, washed in a warm detergent solution, and rinsed again in warm, running tap water. They were then soaked in Cidex[a] solution for a minimum of ten minutes. After this they were rinsed in running tap water and finally in sterile water. The mouth pieces and J-valves were placed on a rack to air dry.

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[a] Arbrook Inc., Arlington, Texas 76010

Procedures for Data Reduction

The data reduction procedures necessary to calculate minute heart rate and oxygen uptake are considered in this section.

Heart rate determination. Minute heart rate was calculated from the ratio of the electrocardiograph paper speed in millimeters per minute to the average R-R interval determined from the electrocardiogram (ECG) of the last ten seconds of each minute of exercise. The number of R-waves and the distance between the first and last R-wave were used to determine the average R-R interval. Since the paper speed of the recorder was 25 millimters per second which equals 1500 millimeters per minute, the quotient of 1500 millimeters per minute divided by the R-R interval in millimeters provided the number of R-waves or heart rate per minute.

Oxygen uptake determination. The parameters necessary for calculating oxygen uptake values were: (1) the collection time, in seconds, of expired air, (2) the gas fractions of expired O_2 and CO_2, (3) the volume of expired air, (4) the temperature of expired air, and (5) the atmospheric pressure during collection.

Atmospheric pressure and expired air temperature readings were used to obtain the appropriate correction factor for converting warm, moist gas samples to standard temperature and pressure, dry (STPD). The chart of

conversion factors[28] is presented in Table 18, Appendix G, page 126.

All calculations were performed on a Hewlett Packard model 97 programable calculator. The volume of expired air was corrected as previously noted in the section on oxygen uptake equipment, page 31, by applying the correction factor: Volume = .9813X - .083. This volume was then converted to a minute volume ($\dot{V}_E$) by the following formula: ($\dot{V}_{STPD}$ x 60 seconds) $\div$ collection time. Oxygen uptake was determined by the following formulas:

$$F_{E_{N_2}} = 1.00 - (F_{E_{O_2}} + F_{E_{CO_2}})$$

$$\dot{V}_I = \frac{\dot{V}_E \times F_{E_{N_2}}}{F_{I_{N_2}}}$$

$$\dot{V}O_2 = (F_{I_{O_2}} \times \dot{V}_I) - (F_{E_{O_2}} \times \dot{V}_E)$$

$F_{I_{O_2}}$ and $F_{I_{N_2}}$ were considered constants at .2093 and .7904, respectively. The Respiratory Quotient (R.Q.) was also determined by the formula:

$$R.Q. = \frac{\dot{V}_E \times F_{E_{CO_2}}}{\dot{V}O_2}$$

Method of Statistical Analysis

The statistical analyses were performed utilizing the Statistical Analysis System (SAS) library programs GLM,

STEPWISE, ANOVA, and MEANS. The 0.05 level was adopted as the test of statistical significance for this study.

Linear regression. The GLM and STEPWISE procedures were used for the linear regression analysis. Simple linear regression analyses were performed on the parameters of oxygen uptake ($\dot{V}O_2$) versus walking velocity squared (v^2) and $\dot{V}O_2$ versus heart rate (HR) on each subject for each of the three modes of walking. The means of the slopes and intercepts of the individual regression equations obtained in these analyses were used to generate composite regression equations for each walking mode. The individual regression equations for $\dot{V}O_2$ versus HR obtained in the first analysis were used to predict the subject's individual maximal aerobic power (MAP) from maximum heart rate values determined on the maximal treadmill exercise test. Multiple regression analyses were performed on MAP determined from the maximal test and submaximal heart rates obtained during level walking. Three sets of analyses were performed for each of the three walking modes. The first set of multiple regression analyses involved the parameters of MAP versus the independent variables of heart rate for each of the seven walking velocities. The second set of analyses included heart rates for only the first five walking velocities. The final set of analyses involved using the STEPWISE procedure in which heart rate values of the different walking velocities were systematically added in a forward

direction until the best regression equation was obtained with the least number of independent variables.

In addition to generating slopes and intercepts for regression equations, the procedures GLM and STEPWISE provided coefficients of determination (R^2) for each analysis.

Analysis of variance. The analysis of variance procedure ANOVA was used to analyze the slopes and intercepts of the simple regression equations. Analysis of variance was utilized to compare the oxygen uptake values associated with each walking velocity across all walking modes. This procedure was also used to compare the predicted MAP's from the submaximal walking modes with the MAP determined from the maximal treadmill exercise test. Duncan's test, an adjunct procedure to ANOVA, was used as a follow-up test to analyze the simple effects.

Means and standard deviations. The MEANS procedure was used to compute the means and standard deviations for oxygen uptake and heart rate for the three walking modes. The paired t-test, an adjunct procedure to the MEANS procedure, was used to test for differences in the fourth and fifth minute heart rates for segmental walking.

CHAPTER IV

ANALYSIS OF DATA

A major purpose of this investigation was to determine the viability of level walking as a submaximal exercise test for predicting maximal aerobic power. Three modes of walking, segmental, circular, and treadmill, were considered. The question whether or not steady state conditions could be achieved during segmental walking was a fundamental concern. An additional purpose of the study was to examine the differences in energy cost between treadmill and floor walking. The ability to predict energy cost from walking velocity was a secondary consideration. A description of the subjects and the analyses are included in this chapter. Linear regression analysis was used to evaluate the oxygen uptake and heart rate responses to each walking mode and in the prediction of energy cost from walking velocity. Multiple regression analysis aided the prediction of maximal aerobic power. Analysis of variance was used to test the differences in mean slopes and intercepts of the regression lines, to compare oxygen uptake values at each walking velocity for the three walking modes, and in the comparison of maximal aerobic power values. The paired t-test was utilized to determine if steady state conditions existed during segmental walking.

Subjects of the Study

Thirty normal, young adult males were employed as subjects for this study. They ranged in age from 18 to 37 years with a mean of 28.3 years. The weight of the subjects ranged from 61.08 to 99.20 kilograms with a mean weight of 77.16 kilograms. A summary of the subjects ages and weights with the means and standard deviations is presented in Table 19, Appendix H, pages 128 to 129.

Linear Regression Analysis

Simple regression equations were calculated on each subject for oxygen uptake ($\dot{V}O_2$) versus velocity squared (v^2) and for $\dot{V}O_2$ versus heart rate (HR) for each of the three modes of walking. Simple coefficients of determination (R^2) were also calculated. The slopes, intercepts, and R^2 values together with the F value and its associated p value for these analyses are presented in Tables 20 to 25, Appendix I, pages 131 to 142. Composite regression equations were calculated from the individual regression equations by computing the means for slopes and intercepts. Composite R^2's were similarly determined. The composite regression equations with standard errors and mean R^2 values are presented in Table 1, page 51. The composite regression lines for each of the three modes of walking are graphically compared in Figures 18 and 19, pages 52 and 53 for $\dot{V}O_2$ versus v^2 and $\dot{V}O_2$ versus HR, respectively. The

Table 1

Composite Regression Equations[a] and Mean R^2 Values[b] with Standard Errors for Three Modes of Walking ($n = 30$)

A. Oxygen Uptake (ml O_2/kg-min) versus Velocity Squared [$(m/min)^2$]

Mode of Walking	Equation	Mean R^2
Segmental	$E = .00136v^2(\pm.00004) + 5.22(\pm.157)$	$.96(\pm.0010)^*$
Circular	$E = .00094v^2(\pm.00002) + 6.10(\pm.168)$	$.98(\pm.0003)^*$
Treadmill	$E = .00093v^2(\pm.00002) + 5.94(\pm.150)$	$.98(\pm.0005)^*$

B. Oxygen Uptake (ml O_2/kg-min) versus Heart Rate (beats/min)

Mode of Walking	Equation	Mean R^2
Segmental	$E = 0.399HR(\pm.0124) - 23.537(\pm1.457)$	$.94(\pm.0026)^*$
Circular	$E = 0.315HR(\pm.0088) - 16.028(\pm0.896)$	$.94(\pm.0018)^*$
Treadmill	$E = 0.377HR(\pm.0138) - 21.906(\pm1.429)$	$.92(\pm.0029)^*$

[a] Equations generated from the means of the slopes and intercepts of the individual simple regression equations.

[b] Values obtained from the means of the individual R^2 values calculated adjunct to the simple regression analysis.

* All thirty of the individual R^2 values were significant at the .05 level.

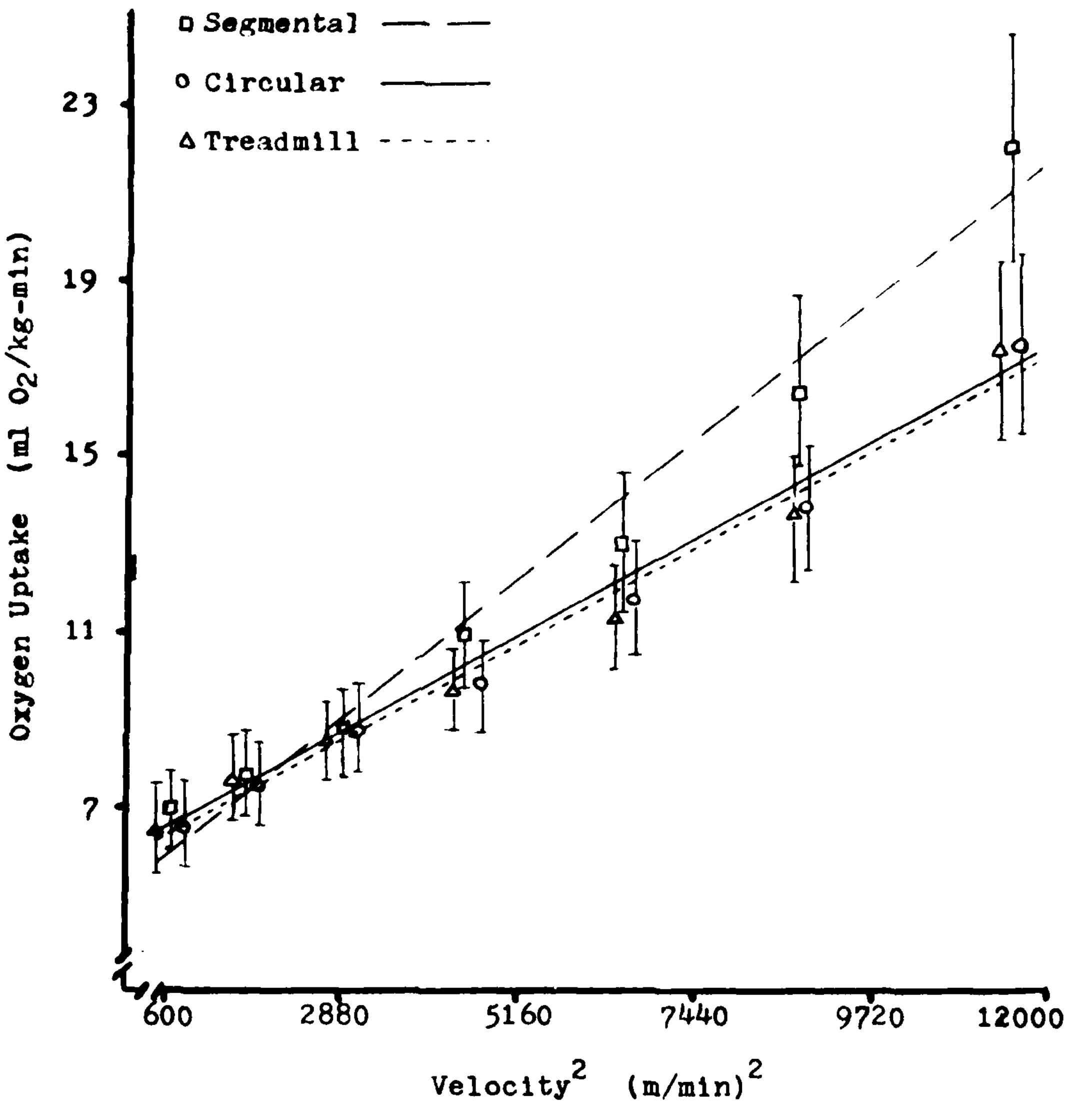

Figure 18

Composite Regression Lines with Group Means and Standard Deviations for Oxygen Uptake versus Velocity Squared for Three Modes of Walking

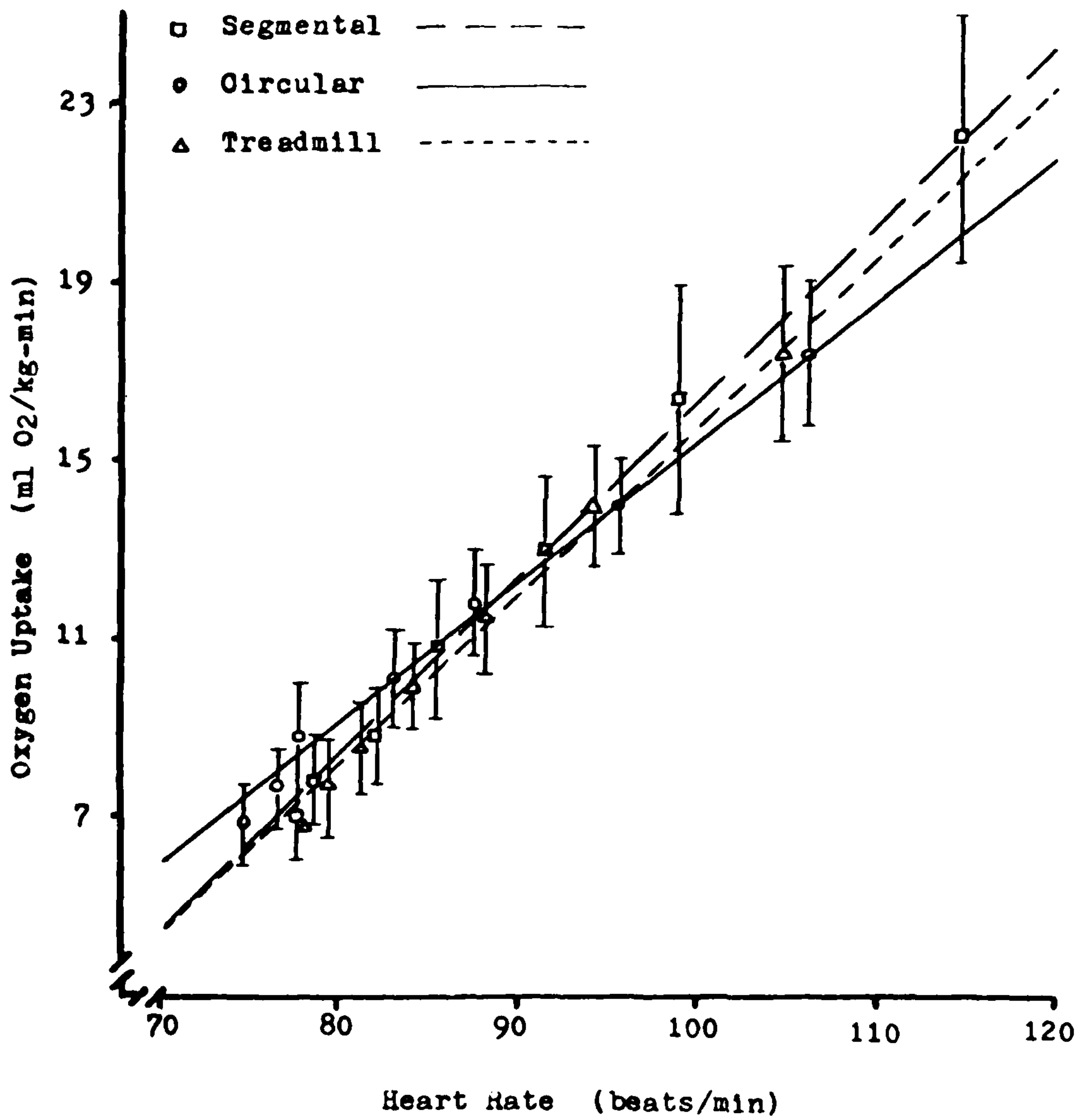

Figure 19

Composite Regression Lines with Group Means and Standard Deviations for Oxygen Uptake versus Heart Rate for Three Modes of Walking

observed group means and standard deviations are superimposed on the regression lines. The group means and standard deviations for $\dot{V}O_2$ and HR associated with walking velocities for the three modes of walking are presented in Table 2, page 55.

Multiple Regression Equations

Multiple regression equations were calculated in order to predict maximal aerobic power (MAP) determined during the treadmill exercise test, from the submaximal heart rate data obtained during level walking. A forward selection, stepwise analysis was used to determine the best prediction with the least number of independent variables. Equations were also determined by including all heart rate values association with the seven walking velocities and, again, on the five slower walking velocities. Coefficients of determination (R^2) were calculated for each equation. The analyses were repeated for each of the three modes of walking. The multiple regression equations including R^2, F, and p values are presented in Table 3, pages 56 and 57.

Analysis of Variance

Analysis of variance was used to test for mean differences in mean slopes and intercepts of regression lines for $\dot{V}O_2$ versus v^2 and $\dot{V}O_2$ versus HR for each mode of walking. Group means and standard errors are presented in

Table 2

Group Means and Standard Deviations for Oxygen Uptake and Heart Rate Associated with Velocity for Three Modes of Walking (n = 30)

A. Oxygen Uptake (ml O_2/kg-min)

Walking Mode	Velocity (m/min) 26.82	40.23	53.64	67.06	80.47	93.88	107.29
Segmental	7.05(±1.00)	7.78(±0.91)	8.88(±1.01)	10.89(±1.30)	13.00(±1.59)	16.38(±2.27)	22.22(±2.59)
Circular	6.90(±0.95)	7.76(±0.87)	8.89(±1.12)	10.23(±1.00)	11.83(±1.25)	14.13(±1/31)	17.37(±1.71)
Treadmill	6.86(±0.87)	7.82(±0.95)	8.63(±1.03)	9.80(±1.04)	11.45(±1.23)	13.70(±1.41)	17.42(±2.01)

B. Heart Rate (beats/min)

Walking Mode	Velocity (m/min) 26.82	40.23	53.64	67.06	80.47	93.88	107.29
Segmental	77.6(±11.4)	78.5(±10.6)	81.7(±11.0)	85.4(±12.2)	91.1(±10.5)	98.7(±11.6)	114.5(±13.6)
Circular	74.6(±10.6)	76.5(±10.3)	78.3(±10.3)	82.9(±10.6)	88.1(±11.8)	95.6(±11.1)	106.0(±12.2)
Treadmill	77.9(±13.4)	79.0(±12.5)	80.6(±11.2)	84.2(±10.9)	88.1(±11.1)	94.1(±11.0)	104.4(±11.0)

Table 3

Multiple Regression Equations, R^2, F, and p Values for Maximal Aerobic Power (ml O_2/kg-min) versus Submaximal Heart Rate

A. Segmental Walking

Type of Selection	Independent Variable[a]	Equation	R^2	F	p
Forward, Stepwise	X_1-X_7	$MAP = 97.83+1.02X_1-0.82X_2-0.74X_3+0.68X_4-0.79X_5+0.60X_6-0.47X_7$	.54*	3.52	.0117
Inclusive	X_1-X_7	$MAP = 97.83+1.02X_1-0.82X_2-0.74X_3+0.68X_4-0.79X_5+0.60X_6-0.47X_7$	.54*	3.52	.0117
Inclusive	X_1-X_5	$MAP = 96.34+0.96X_1-0.95X_2-0.66X_3+0.69X_4-0.62X_5$	.44*	3.83	.0109

B. Circular Walking

Type of Selection	Independent Variable[a]	Equation	R^2	F	p
Forward, Stepwise	X_2-X_5,X_7	$MAP = 84.01-0.43X_2+1.04X_3-1.45X_4+0.77X_5-0.34X_7$	.59*	6.84	.0004
Inclusive	X_1-X_7	$MAP = 82.57-0.26X_1-0.32X_2+1.08X_3-1.34X_4+0.74X_5+0.21X_6-0.49X_7$	.60*	4.74	.0023
Inclusive	X_1-X_5	$MAP = 78.12-0.14X_1-0.33X_2+1.22X_3-1.77X_4+0.60X_5$	.57*	6.41	.0006

Table 3 - continued

C. Treadmill Walking					
Type of Selection	Independent Variable[a]	Equation	R^2	F	p
Forward, Stepwise	X_6, X_7	MAP = $95.65+0.56X_6-0.99X_7$	.43*	9.96	.0006
Inclusive	X_1-X_7	MAP = $101.73+0.37X_1-0.20X_2-0.44X_3+0.20X_4+0.10X_5+0.59X_6-1.12X_7$	.48*	2.75	.0341
Inclusive	X_1-X_5	MAP = $90.30+0.82X_1-0.41X_2+0.12X_3-0.83X_4-0.19X_5$	.33*	2.36	.0706

[a] Mean heart rate values associated with respective walking velocities;
X_1 = heart rate at 26.82 m/min
X_2 = heart rate at 40.23 m/min
X_3 = heart rate at 53.64 m/min
X_4 = heart rate at 67.06 m/min
X_5 = heart rate at 80.47 m/min
X_6 = heart rate at 93.88 m/min
X_7 = heart rate at 107.29 m/min

* Significant at the .05 level

Table 4, page 59. The differences in the group means are resented in Table 5, page 60. As can be seen from Table 5, part A, the slopes and intercepts of $\dot{V}O_2$ versus v^2 were significantly different for segmental versus circular and treadmill walking. The slopes and intercepts for circular and treadmill walking were not significantly different. In Table 5, part B, it can be seen that the slopes and intercepts of circular walking were significantly different from segmental and treadmill walking for $\dot{V}O_2$ versus HR.

The differences in oxygen uptake associated with the seven walking velocities for the three walking modes were analyzed with the analysis of variance. The differences in group means are presented in Table 6, pages 61 and 62. This analysis demonstrated that the $\dot{V}O_2$ for the four upper velocities for segmental walking were significantly different than those of circular and treadmill walking. There were no significant differences in $\dot{V}O_2$ between circular and treadmill walking.

Analysis of variance was also used to test the differences between predicted MAP from the three submaximal level walking modes and MAP determined on the treadmill exercise test. The predicted MAP was calculated from maximum heart rate determined during the maximal exercise test and the individual regression equations of $\dot{V}O_2$ versus HR for each walking mode. The group means, standard errors, and differences in means are presented in Table 7, page 63. As

Table 4

Mean Slopes, Intercepts, and Standard Errors
for Three Modes of Walking
(n = 30)

A. Oxygen Uptake versus Velocity Squared

Mode of Walking	Mean Slope	Mean Intercept
Segmental	0.00136 (±0.00004)	5.218 (±0.1572)
Circular	0.00094 (±0.00002)	6.097 (±0.1676)
Treadmill	0.00093 (±0.00002)	5.942 (±0.1497)

B. Oxygen Uptake versus Heart Rate

Mode of Walking	Mean Slope	Mean Intercept
Segmental	0.3985 (±0.0124)	-23.537 (±1.4566)
Circular	0.3153 (±0.0088)	-16.028 (±0.8959)
Treadmill	0.3769 (±0.0138)	-21.906 (±1.4291)

Table 5

Differences in Mean Slopes and Intercepts
for Three Modes of Walking
(n = 30)

A. Oxygen Uptake versus Velocity Squared

	Circular Walking		Treadmill Walking	
	Slope	Intercept	Slope	Intercept
Segmental	0.00042*	0.8787*	0.00043*	0.7241*
Circular			0.00001	0.1546

B. Oxygen Uptake versus Heart Rate

	Circular Walking		Treadmill Walking	
	Slope	Intercept	Slope	Intercept
Segmental	0.0832*	7.5092*	0.0216	1.6317
Circular			0.0617*	5.8775*

* Significant at the .05 level, Duncan's multiple comparison procedure.

Table 6

Differences between Group Means for Oxygen Uptake ($ml\ O_2$/kg-min) at Seven Velocities over Three Walking Modes ($n = 30$)

A. 26.82 m/min

	Circular	Treadmill
Segmental	0.154	0.187
Circular		0.032

B. 40.23 m/min

	Circular	Treadmill
Segmental	0.022	0.043
Circular		0.065

C. 53.64 m/min

	Circular	Treadmill
Segmental	0.010	0.253
Circular		0.263

D. 67.06 m/min

	Circular	Treadmill
Segmental	0.661*	1.092*
Circular		0.431

Table 6 - continued

E. 80.47 m/min

	Circular	Treadmill
Segmental	1.163*	1.543*
Circular		0.380

F. 93.88 m/min

	Circular	Treadmill
Segmental	2.253*	2.677*
Circular		0.424

G. 107.29 m/min

	Circular	Treadmill
Segmental	4.850*	4.798*
Circular		0.052

* Significant at the .05 level, Duncan's multiple comparison procedure.

Table 7

Group Means, Standard Errors, and Differences between Means for Predicted[a] and Determined[b] Maximal Aerobic Power (ml O_2/kg-min) (n = 30)

A. Group Means and Standard Errors

Mode	Mean
Segmental	51.988 (±1.276)
Circular	43.676 (±1.134)
Treadmill	49.537 (±1.512)
Exercise Test	44.385 (±1.487)

B. Differences between the Means

	Circular	Treadmill	Exercise Test
Segmental	8.312*	2.451	7.604*
Circular		5.862*	0.709
Treadmill			5.153*

[a] MAP predicted from individual regression equations of $\dot{V}O_2$ versus HR.

[b] MAP determined from the maximal treadmill exercise test.

* Significant at the .05 level, Duncan's multiple comparison procedure.

noted the MAP's predicted from circular walking and determined from the maximal exercise test were similar and both were significantly different from the MAP's predicted from the treadmill and segmental walking modes. Treadmill and segmental walking modes were not significantly different.

The Paired t-test

The fourth and fifth minute heart rates of segmental walking were analyzed to see if they were similar. The paired t-test was used to test the differences between the fourth and fifth minute heart rates associated with each of the seven walking velocities. The group means, standard deviations, mean differences, t, and p values are presented in Table 8, page 65. No significant differences were noted.

Table 8

Group Means, Standard Deviations, Differences between Means, t, and p Values for Fourth and Fifth Minute Heart Rates for Segmental Walking (n = 30)

Velocity (m/min)	Heart Rate 4th minute	Heart Rate 5th minute	Mean Difference	t	p
26.82	77.4(±11.5)	77.6(±11.4)	-0.2	-0.18	0.86
40.23	79.7(±11.0)	78.5(±10.6)	1.2	1.43	0.16
53.64	80.5(±10.4)	81.7(±11.0)	-1.2	-1.79	0.08
67.06	85.3(±10.9)	85.4(±12.2)	-0.1	-0.08	0.94
80.47	91.5(±11.6)	91.1(±10.5)	0.4	0.57	0.57
93.88	98.3(±12.1)	98.7(±11.6)	-0.4	-0.61	0.55
107.29	114.2(±14.0)	114.5(±13.6)	-0.3	-0.57	0.58

CHAPTER V

DISCUSSION OF THE RESULTS

This study was concerned with the investigation of level walking as a submaximal exercise test and its ability to predict maximal aerobic power. Three modes of walking were considered; segmental, circular, and treadmill walking. Since segmental walking was non-continuous in nature, i.e. it involved turns at the end of each interval of walking, a basic question was whether or not steady state conditions would be achieved during this mode of walking. To clarify whether or not there is a difference in energy cost between treadmill and floor walking, a comparison of the energy cost between the three modes of walking was made. The prediction of energy cost from walking velocity was a secondary consideration. This section will include a discussion of the results as related to the stated problems and subproblems. Topics considered are oxygen uptake and heart rate responses during the three modes of walking, the prediction of energy cost from walking velocity, the prediction of maximal aerobic power from the proposed submaximal exercise tests of level walking, and the clinical implications.

Oxygen Uptake and Heart Rate

The linear regression analysis of oxygen uptake ($\dot{V}O_2$) versus velocity squared (v^2) indicated that both the mean slope and mean intercept for segmental walking were significantly different from those obtained for either treadmill or circular walking. The fact that the slopes and intercepts were not different for treadmill and circular walking supports Ralston's latest study[31] which equates these forms of walking. This also supports some of the data of Wyndham et al[41] in which the energy cost of road walking and treadmill walking were compared over three velocities. The oxygen consumption was higher for road walking at the two slower velocities, but similar at the faster velocity. The results of the Daniels et al[14] study, in which road walking was 9-10% higher in energy cost than treadmill walking, disagrees with the present study. As Ralston hypothesized[31] this may be due to the nature of the walking surfaces.

As was seen in Table 5, page 60, the slopes and intercepts of $\dot{V}O_2$ versus walking velocity squared were significantly different for segmental walking compared to circular and treadmill walking. This difference in energy cost could be attributed to the turns involved in segmental walking. The number of turns required during the five minute walk increased proportionately with walking velocity. The increased oxygen consumption necessary to negotiate

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these terms on the 13.4 meter walkway was significant at the fourth velocity, 67.06 meters per minute, as was demonstrated in Table 6, page 61. Since the energy cost of segmental walking appeared to be a function of the number of turns required per unit of time, it was obvious that the length of walkway was an important consideration. Accordingly, differences in energy cost should occur at lower velocities on a shorter walkway and at higher velocities on a longer walkway. Hypothetically, for a 26 meter walkway the differences in energy cost would not occur before the seventh walking velocity, 107.29 meters per minute.

Although there were differences in energy cost, an additional concern was whether or not steady state conditions could be achieved during the segmental walking. Non-significant differences in heart rate during the fourth and fifth minutes of segmental walking demonstrated that steady state could be maintained. This was evident from the t-test results presented previously in Table 8, page 65.

A linear regression analysis was also performed on oxygen uptake versus heart rate associated with each walking velocity. The analysis of slopes and intercepts of the regression lines demonstrated that the response to circular walking was statistically different from treadmill and segmental walking. This was true for both the slope

and the intercept. No differences were found between the slope and intercepts for treadmill and segmental walking. The major contributing factor in this relationship appeared to be the discrepancies in heart rates at the lower four walking velocities. The heart rates at these speeds were similar for treadmill and segmental walking, but lower during circular walking. Apparently the effect of the lower heart rates for circular walking had a greater enfluence than increasing $\dot{V}O_2$ found for segmental walking when plotting $\dot{V}O_2$ versus heart rate.

Predicting Energy Cost from Walking Velocity

To predict the energy cost from walking velocity, regression equations were developed for each of the three modes of level walking used in the study. These equations were presented earlier in Table 1, page 51. The equations are also presented in Table 9, page 70, where they are compared to similar equations of other studies. Also included in Table 9 is the predicted oxygen uptake from each equation for a slow, comfortable walking velocity of 67.06 m/min (2.5 MPH). This prediction appears to be similar for all equations. For graphical comparisons the regression lines of each equation are presented in Figure 20, page 71. The regression lines appear to be very similar. The two most divergent regression lines were those associated with segmental walking in the present study and the

Table 9

Regression Equations for Predicting Energy Cost ($ml\ O_2/kg\text{-}min$) from Walking Velocity

Author, Year	n	Mean Age		Equation	$\dot{V}O_2$ [a]
Rohrig (1978)	30	28	1.[b]	$E = .001362v^2 + 5.22$	11.34
			2.	$E = .000943v^2 + 6.10$	10.34
			3.	$E = .000934v^2 + 5.94$	10.14
Blessey et al[6] (1976)	20	39		$E = .000811v^2 + 7.55$	11.20
Griffith et al[20] (1976)	7	32		$E = .000909v^2 + 6.06$	10.15
Corcoran & Brengelman[10] (1970)	32, ♀ + ♂	38		$E = .001005v^2 + 6.15$	10.67
Molen & Rozendal[25] (1966)	12, ♀ + ♂	22		$E = .001045v^2 + 7.06$	11.76
Grimby & Soderholm[21] (1962)	36	32		$E = .001224v^2 + 5.80$	11.30
Bobbert[7] (1960)	2	25 & 32		$E = .000972v^2 + 6.72$	11.09
Ralston[32]	19, ♀ + ♂	32		$E = .001097v^2 + 6.00$	10.93

[a] $\dot{V}O_2$ predicted for a walking velocity of 67.06 m/min

[b] 1.= Segmental, 2.= Circular, 3.= Treadmill

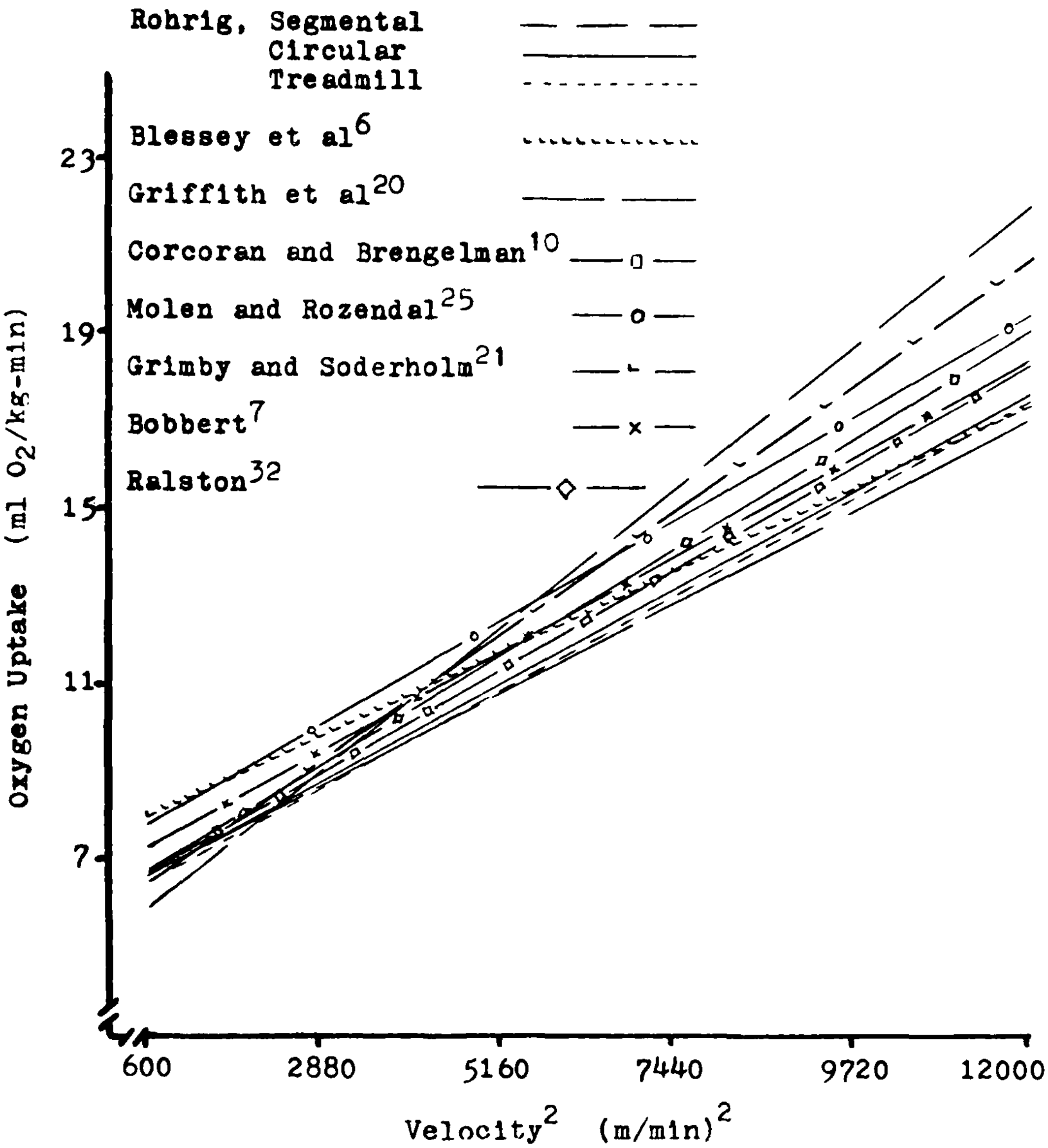

Figure 20

Regression Lines for Energy Cost versus Walking Velocity Squared from Present and Previous Studies

regression line reported by Grimby and Soderholm[21]. The slopes of these regression lines appear to be larger and the intercept less than the other lines.

Grimby and Soderholm[21] reported a correlation coefficient of .87 for their regression equation. No other previous study reported such a statistic. An estimate of the correlation coefficient for the regression equations developed in the present study was obtained by taking the square root of the coefficient of determination (R^2). The representative correlation coefficients obtained in this manner were .98, .99, and .99 for the composite regression equations for segmental, circular, and treadmill walking, respectively. The results substantiate the previously reported[6,7,10,20,21,25,32] linear relationship that exists between energy cost and the square of the walking velocity.

The regression equations for predicting $\dot{V}O_2$ from walking velocity developed in this study were found to be quite accurate. The mean $\dot{V}O_2$ observed from the thirty subjects at each velocity was compared to the $\dot{V}O_2$ predicted from the equations for segmental, circular, and treadmill walking in Table 10, pages 73 and 74. Percent errors shown in this table were calculated from the following equation:

$$\text{Percent Error} = \frac{\text{Observed - Predicted}}{\text{Observed}} \times 100$$

Table 10 demonstrates the low percent errors for all equations; the highest mean error was 0.13%.

Table 10

Group Means and Percent Errors[a] for Oxygen Uptake (ml O_2/kg-min) Observed and Predicted from Individual Regression Equations[b] of Oxygen Uptake versus Velocity Squared for Three Modes of Walking
(n = 30)

A. [illegible] Walking

Observations, Predictions, Mean Errors	Velocity (m/min) 26.82	40.23	53.64	67.06	80.47	93.88	107.29	Group Percent Error	Group Standard Error
Mean Oxygen Uptake Observed (Standard Error)	7.05 (±0.18)	7.78 (±0.17)	8.88 (±0.18)	10.89 (±0.24)	13.00 (±0.29)	16.38 (±0.41)	22.22 (±0.47)		
[illegible] Predicted ([illegible] Error)	6.20 (±0.15)	7.41 (±0.16)	9.14 (±0.17)	11.34 (±0.21)	14.06 (±0.27)	16.60 (±0.67)	20.9[illegible] (±0.45)		
[illegible] Error ([illegible] Error)	11.9 (±.77)	4.4 (±1.86)	-3.1 (±.78)	-4.6 (±1.17)	-8.5 (±1.39)	-5.1 (±1.08)	5.9 (±.53)	0.13	2.78

	Velocity (m/min) [illegible]	[illegible].23	53.64	67.06	80.47	93.88	107.29	Group Percent Error	Group Standard Error
[illegible]	[illegible]	[illegible]	8.89 (±0.20)	10.23 (±0.18)	11.83 (±0.23)	14.13 (±[illegible].24)	17.37 (±0.3[illegible])		
[illegible]	[illegible]	[illegible] (±[illegible].17)	[illegible] (±[illegible].17)	10.34 (±0.19)	12.20 (±0.21)	14.40 (±0.24)	16.95 (±0.29)		
[illegible]		[illegible]	[illegible]	-1.1 (±.66)	-3.2 (±.57)	-2.0 (±.49)	2.3 (±.35)	0.01	0.81

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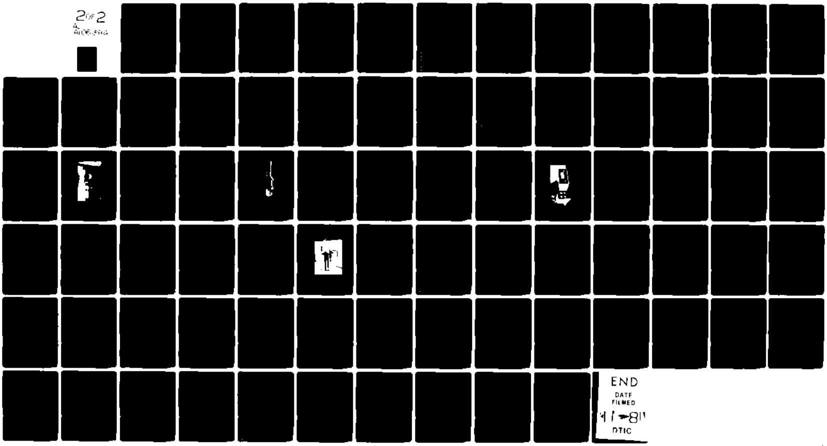

Table 10 - continued

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] Percent Error	[illegible] Error
Mean [illegible] Observed	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Standard Error	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Mean [illegible] Predicted	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Standard Error	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Mean Percent Error	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Standard Error	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		

[a] Percent Error = (observed - predicted)/observed, x 100

[b] Equations generated from the slopes and intercepts for simple linear regression analysis of each subject.

Maximal Aerobic Power Prediction

Maximal aerobic power (MAP) was predicted from each of the three submaximal exercise tests of the three different modes of level walking. As was shown in Table 7, page 63, segmental and treadmill walking over predicted MAP determined from the maximal exercise test. The difference between MAP predicted from circular walking and MAP determined from the maximal exercise test was statistically nonsignificant at the .05 level. The percent error and standard errors in predicting MAP from the three submaximal exercise tests of segmental, circular, and treadmill level walking are shown in Table 11, page 76. Percent error was calculated as noted in the preceding paragraph. The largest percent error was -19.5% associated with segmental walking.

In an effort to generate a more accurate method of predicting MAP, multiple regression equations were calculated for MAP versus submaximal heart rates at different walking velocities. A forward selection analysis was used to determine the best prediction with the least number of independent variables. Multiple regression analyses were also calculated for all seven heart rates and heart rates associated with the five slower walking velocities. These analyses were conducted for each of the three modes of walking. The equations were presented in the previously mentioned Table 3, pages 56 and 57. The coefficients of determination for the stepwise analyses were .54, .59, and

Table 11

Group Means, Percent Errors[a], and Standard Errors for Maximal Aerobic Power (ml O_2/kg-min) Predicted from Individual Regression Equations[b] versus Determined from Maximal Exercise Test[c] (n = 30)

Mode	MAP Predicted	MAP Determined	Percent Error
Segmental	51.99 (±1.28)	44.38 (±1.49)	-19.5 (±0.66)
Circular	43.68 (±1.13)	44.38 (±1.49)	-0.4 (±0.59)
Treadmill	49.54 (±1.51)	44.38 (±1.49)	-13.8 (±0.74)

[a] Percent Error = [(observed - predicted)/observed] × 100

[b] Prediction of maximal aerobic power based on maximum heart rate obtained from the maximal exercise test and the individual regression equations of $\dot{V}O_2$ versus HR for each mode of walking.

[c] Maximal aerobic power determined from the maximal treadmill exercise test.

.43 for segmental, circular, and treadmill walking, respectively. (This might be compared with associated estimated correlation coefficients of .73, .77, and .66, respectively.) The R^2 values for the equations which included all seven heart rate values were .54, .60, and .48 for segmental, circular, and treadmill walking, respectively. (The representative correlation coefficients were .73, .78, and .69, respectively.) Finally, .44, .57, and .33 were the R^2 values for segmental, circular, and treadmill walking, respectively, from the equations including only the five heart rates of the slower velocities. (The representative correlation coeffiecients were .67, .76, and .57, respectively.) The coefficients of determination ranged from .33 to .60 indicating the degree of variability in MAP that could be accounted for by the independent variables. All R^2 values were significant at the .05 level.

The group means, percent errors, and standard errors for predicting MAP from the multiple regression equations are presented in Table 12, pages 78 and 79. Percent error was calculated as previously noted on page 72. The percent error ranged from -0.003 to -3.99% which were low in contrast to the maximum percent error of -19.5% found on the prediction of MAP from the composite regression equations.

The relatively high and statistically significant R^2 values provide credibility to the method of predicting MAP from heart rate values associated with submaximal walking

Table 12

Group Means, Percent Errors[a], and Standard Errors
for Maximal Aerobic Power (ml O_2/kg-min)
Predicted from Multiple Regression
Equations versus Determined from
Maximal Exercise Test[b]
(n = 30)

A. Segmental Walking

Type of Selection	Independent Variable[c]	MAP Predicted	MAP Determined	Percent Error
Forward, Stepwise	X_1-X_7	44.06 ($\pm$0.20)	44.38 ($\pm$1.49)	-0.70 ($\pm$2.43)
Inclusive	X_1-X_7	44.06 ($\pm$0.20)	44.38 ($\pm$1.49)	-0.70 ($\pm$2.43)
Inclusive	X_1-X_5	44.70 ($\pm$0.18)	44.38 ($\pm$1.49)	-2.80 ($\pm$2.67)

B. Circular Walking

Type of Selection	Independent Variable[c]	MAP Predicted	MAP Determined	Percent Error
Forward, Stepwise	X_2-X_5,X_7	44.04 ($\pm$0.21)	44.38 ($\pm$1.49)	-0.40 ($\pm$2.14)
Inclusive	X_1-X_7	45.37 ($\pm$0.21)	44.38 ($\pm$1.49)	-3.99 ($\pm$2.04)
Inclusive	X_1-X_5	43.98 ($\pm$0.21)	44.38 ($\pm$1.49)	-0.30 ($\pm$2.15)

Table 12 - continued

C. Treadmill Walking				
Type of Selection	Independent Variable[c]	MAP Predicted	MAP Determined	Percent Error
Forward, Stepwise	X_6, X_7	44.98 (±0.18)	44.38 (±1.49)	-3.40 (±2.60)
Inclusive	X_1-X_7	43.63 (±0.19)	44.38 (±1.49)	-.003 (±2.54)
Inclusive	X_1-X_5	44.83 (±0.15)	44.38 (±1.49)	-3.10 (±2.74)

[a] Percent Error = [(observed - predicted)/observed] x 100

[b] Maximal aerobic power determined from the maximal treadmill exercise test.

[c] Mean heart rate values associated with respective walking velocities:

X_1 = heart rate at 26.82 m/min
X_2 = heart rate at 40.23 m/min
X_3 = heart rate at 53.64 m/min
X_4 = heart rate at 67.06 m/min
X_5 = heart rate at 80.47 m/min
X_6 = heart rate at 93.88 m/min
X_7 = heart rate at 107.29 m/min

velocities. The relatively low percent errors observed in this prediction indicate the degree of accuracy that can be achieved. The predictive capability of all of the equations generated is considered good, however, the best prediction, logically, was obtained from the multiple regression equation that used all seven heart rate values as the independent varables.

Clinical Implications

Individualized patient counseling and exercise prescription requires a knowledge of the persons work capacity. Accurate assessment of work capacity can be accomplished through graded exercise tests with special testing equipment, however, certain disadvantages such as cost, noise, and motor skill have limited the clinical utility of these devices. Possible differences in energy cost between the different modes of exercise such as treadmill versus floor walking have restricted the application of this type of test data.

Level walking as an approach to submaximal exercise testing has been recognized as a viable alternative method. Bassey et al[5] considered the advantages to this method very acceptable to the clinical situation. The appropriateness of the test to a wider range of patients was cited because of the familiar form of the exercise which could be used safely by the elderly and orthopedically involved patient.

They also noted that the correlation with the bicycle exercise test was reasonably high (r = .79).

The accepted percent error for predicting MAP from the conventional submaximal bicycle or treadmill tests is ±10%[27]. The largest percent error obtained from the regression equations in the present study was -4.0%. These findings add credence to this form of exercise testing. The next task will be to determine how similar the R^2 and percent error values will compare for independent subject samples and different patient groups.

Although the energy cost of segmental walking was observed to be significantly greater than circular and treadmill walking in this study, the fourth and fifth minute heart rate comparison indicated that steady state conditions could be achieved. This result indicated the degree of credibility for this particular mode of exercise testing which should be available to all clinical facilities.

The non-significant differences in energy cost of treadmill and circular walking indicated that oxygen uptake data is interchangeable for these two types of exercise. Data obtained on the treadmill, therefore, can be validly used in the prescription of exercise training involving floor walking.

CHAPTER VI

SUMMARY AND CONCLUSION

Purpose of the Study

The purpose of this study was twofold: (1) to develop a submaximal exercise test consisting of level walking, and (2) to examine the differences in energy cost of treadmill and floor walking. The ability to predict energy cost from walking velocity was a secondary problem as was verifying steady state conditions during segmental walking.

Procedures

Thirty young, healthy, adult males served as subjects for the study. The subjects were required to walk for five minutes at each of seven velocities over each of the three different modes of walking; segmental, circular, and treadmill. A maximal progressive exercise test on the treadmill was also required. Energy cost was derived from steady state oxygen uptake determination. The open circuit method was utilized. Heart rate was determined from electrocardiograms obtained with a radio telemetry system and electrocardiograph.

<u>Summary of the Results</u>

The results clearly indicated a linear relationship between oxygen uptake ($\dot{V}O_2$) versus walking velocity squared (v^2) and for $\dot{V}O_2$ versus heart rate (HR) for the three modes of walking. The simple linear regression analyses for these parameters yielded significant mean R^2 values of .92 to .98.

The mean slopes and intercepts for the individual simple linear regression equations of $\dot{V}O_2$ versus v^2 provided the basis for developing composite regression equations for predicting energy cost from walking velocity. A separate equation was developed for each of the walking modes; segmental, circular, and treadmill. Analysis of variance of the mean slopes and intercepts indicated that the energy cost of segmental walking was significantly greater than that for circular and treadmill walking. The difference between circular and treadmill walking was statistically non-significant.

Composite equations were similarly generated for $\dot{V}O_2$ versus HR. Analysis of the slopes and intercepts provided significant differences between those of circular walking compared to segmental and treadmill walking.

The prediction of maximal aerobic power (MAP) from the submaximal walking heart rate data was accomplished by using a multiple regression analysis approach. Three separate equations were developed for each walking mode. The first equation was generated from a forward, stepwise regression

analysis procedure. The second equation was generated as a result of using heart rate data from all seven walking velocities. The third equation utilized the heart rates from the five slower velocities as the independent variables. R^2 values ranged from .33 to .60. The percent errors found for predicting MAP were quite low, ranging from -.003 to -3.99%.

As reflected by the non-significant differences in fourth and fifth minute heart rate measurement, steady state conditions were achieved during segmental walking.

Conclusions

Within the scope and limitations of this study as outlined in Chapter I, pages 5 and 6, the following conclusions are justified:

1. Level walking, a clinically appropriate form of exercise, including segmental, circular, and treadmill walking, can be used as a submaximal exercise test for normal subjects to predict MAP with reasonable confidence. Steady state conditions are achieved during segmental walking, and, therefore, it is included as a testing mode.
2. The energy cost of treadmill walking is not different from continuous floor walking. Data obtained from treadmill tests can validly be used in exercise training prescriptions for level walking.

3. The energy cost of walking can be confidently predicted from walking velocity.

Recommendations for Further Study

The results of this study indicated that level walking is a valid approach to submaximal exercise testing in normal subjects. Additional data with patient groups will be necessary to establish its clinical utility.

APPENDIX A

SUBJECT INFORMATION SUMMARY AND CONSENT FORM

SUBJECT INFORMATION SUMMARY

Submaximal Exercise Testing: Treadmill and Floor Walking

1. The purpose of this study is twofold: (1) to investigate the possibilities of level walking as a submaximal exercise test, and (2) to determine if there is a difference in energy requirements for level walking on the treadmill and the floor. Four test sessions of approximately one hour each will be required of each subject. During three of these sessions the subjects will walk at seven velocities on each of the three modes of walking: a treadmill, a circular track, and a segmental walkway. The fourth test session will be a maximum treadmill exercise test to determine maximum aerobic power. Expired air will be collected through a mouth piece, valve, and collection bags. Heart rate will be monitored from a small radio transmitter that the subject will wear on a belt. These parameters will be monitored during each of the velocities and during each testing session.

2. There are no identifiable risks other than those associated with the physical exercise of walking at increasing velocities and grades. A physical examination will be required of all subjects prior to entrance into the study. The only possible discomfort would be muscle fatigue and shortness of breath relative to the treadmill exercise test.

3. The experience should be educational in nature to the subject, and offer potential benefit in improving exercise testing and exercise prescription.

4. The subject is encouraged and should not hesitate to ask any questions concerning the procedures of this study.

5. The subject has the privelege and right to withdraw their consent and discontinue participation in the study at any time without prejudice to the involved persons.

6. Photographs may be taken for purposes of teaching, for display at medical meetings, publication in medical journals, and/or publications in educational brochures, but only upon additional consent of the subject (a sample release/consent form is attached).

7. The information collected from the measurements and interviews with the subject will be identifiable only to the project investigator as originating from a specific subject. The results will only be publicly presented as group findings and not identifiable to individuals in order to protect the subject's privacy.

I have discussed the above points with the subject or his legally authorized representative, using a translator if necessary. It is my opinion that the subject understands the risks, benefits and obligations involved in participation in this project.

____________________ ______________________________

(DATE) (INVESTIGATIOR)

CERTIFICATION OF SUBJECT CONSENT

Project Title: Submaximal Exercise Testing: Treadmill and Floor Walking

Investigator(s): David H. Nielsen, William L. Rohrig

I, ______________________________, hereby certify that I have been told by ______William L. Rohrig______ of the Physical Therapy Graduate Program that I am to participate in a study to be conducted at University Hospitals of the University of Iowa. The procedures of this study have been explained to me. I am aware that investigative procedures for energy cost determination will be employed. I understand the possible discomforts and risks and the possible benefits relating to this research project and that I may withdraw from the study at any time without prejudice to me.

A written summary of what I have been told is attached, and I have been given an adequate opportunity to read it.

I hereby freely consent to take part in this research project.

Signature of Subject: ______________________________

Signature of Auditor-Witness: ______________________________

Date: ____________________

APPENDIX B

PHOTOGRAPH RELEASE FORM

CERTIFICATION OF SUBJECT

Consent and Release for Photographs

PROJECT TITLE: Submaximal Exercise Testing: Treadmill and Floor Walking

INVESTIGATORS David M. Nielsen, William J. Rohrig

I, ______________________________ do hereby give permission for photographs
(subject's name)
to be taken of my participation in the above indicated study. I, also, hereby release said photographs to the indicated investigators for the purpose of teaching, for display at medical meetings, publication in medical journals, and/or publication in educational brochures.

Signature of Subject: ____

Auditor-Witness: ________________________________

Date: ____

APPENDIX C

MEDICAL HISTORY FORM

FORM FOR MEDICAL HISTORY

NAME: ______________________________ DATE: __________

Have you ever had any known indications of, or been treated for, any of the following? (underline applicable item)

	YES	NO
1. High blood pressure? (If "yes", list drugs prescribed and dates taken.)	___	___
2. Chest pain, heart attack, rheumatic fever, heart murmur, irregular pulse or other disorder of the heart or blood vessels?	___	___
3. Cancer, tumor, cyst, or any disorder of the thyroid, skin, or lymph glands?	___	___
4. Diabetes or anemia or other blood disorder?	___	___
5. Sugar, albumin, blood or pus in the urine, or venereal disease?	___	___
6. Any disorder of the kidney, bladder, prostate, breast or reproductive organs?	___	___
7. Ulcer, intestinal bleeding, hepatitis, colitis, or other disorder of the stomach, intestine, spleen, pancreas, liver or gall		

	YES	NO
bladder?	___	___
8. Asthma, tuberculosis, bronchitis, emphysema or other disorder of the lungs?	___	___
9. Fainting, convulsions, migraine headache, paralysis, epilepsy or any mental or nervous disorder?	___	___
10. Arthritis, gout, amputation, sciatica, back pain or other disorder of the muscles, bones, or joints?	___	___
11. Disorder of the eyes, ears, nose, throat or sinuses?	___	___
12. Varicose veins, phlebitis, hemorrhoids, hernia or rectal disorder?	___	___
13. Alcholism or drug habit?	___	___
Have you:		
14. Had, or been advised to have, an x-ray, cardiogram, blood or other diagnostic test in the past 5 years?	___	___
15. Been a patient in a hospital, clinic, or other medical facility in the past 5 years? (If so, why?)	___	___
16. Ever had a surgical operation performed or advised?	___	___

	YES	NO
17. Had any oral or respiratory infections in the past week?	___	___

....

DETAILS OF "YES" ANSWERS. Include number of attacks, dates:

Additional questions:

	YES	NO
1. Do you get more short of breath than others your age doing normal daily activities?	___	___
2. Have you ever lost consciousness while exercising or do you get dizzy with exercise?	___	___
3. Do you smoke? If so, how much and for how long?	___	___
4. Do you engage in vigorous activity for at least 30 minutes, 3 times per week? (Enough to induce free sweating?)	___	___

APPENDIX D

SPECIAL EQUIPMENT

This appendix is concerned with the equipment which was designed and constructed in conjunction with this study. This equipment consists of the speed control-tracking system used on the segmental walkway and the speedometer cane developed for the circular walking.

Speed Control-Tracking System

An overhead speed control-tracking system was developed to regulate walking velocity on the segmental walkway. The walkway was previously presented in Figure 2, page 19. The system consisted of a motorized continuous chain to which a rubber, foam ball was attached which the subjects followed as it moved along the walkway. The vertical distance from the chain to the floor was 2.4 meters. The vertical distance between the ball and the floor was adjustable. The chain[a] was a light weight, minimum friction, non-lubrication type made of urethane plastic. The chain was reinforced with steel cables. The design permitted high speed operation with little noise and no maintenance problems. The chain was stretched between two gear sprockets[a] in a horizontal loop over the midline of the walkway. The gear sprockets were attached

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[a] Winfred M. Berg, Inc., East Rockaway, New York 11518

to two steel shafts extending downward from two metal plates which were suspended from the ceiling at either end of the walkway. The suspension system consisted of galvanized pipes which were bolted to two additional metal plates that had been permanently secured to the ceiling. Rectangular slots cut in the bottom plates for the pipe attachments, allowed position adjustment of the plates and tension adjustment of the chain. The physical specifications of this mounting system are included in the mechanical drawing presented in Figure 21, page 98. One of the gear sprockets was free turning. The shaft to which it was attached rotated freely in a flanged, ball-bearing unit which was bolted to one of the suspension plates. The attachment shaft of the other sprocket was the drive shaft for a 5:1 ratio gear box[a] which was bolted to the other suspension plate. The power for turning the system was provided by a one-sixth horsepower, 1750 RPM direct current motor[a] which was mounted on top of the gear box. With the 5:1 gear reduction, the speed range of the drive sprocket was 0-350 RPM. The electric motor was controlled by a Ratiopax[a] SCR control package which regulated the amount of direct current flow to the motor. A voltmeter was placed in parallel with the armature windings of the motor. Since the

[a] Boston Gear Division, North American Rockwell, Quincy, Massachusetts 02171

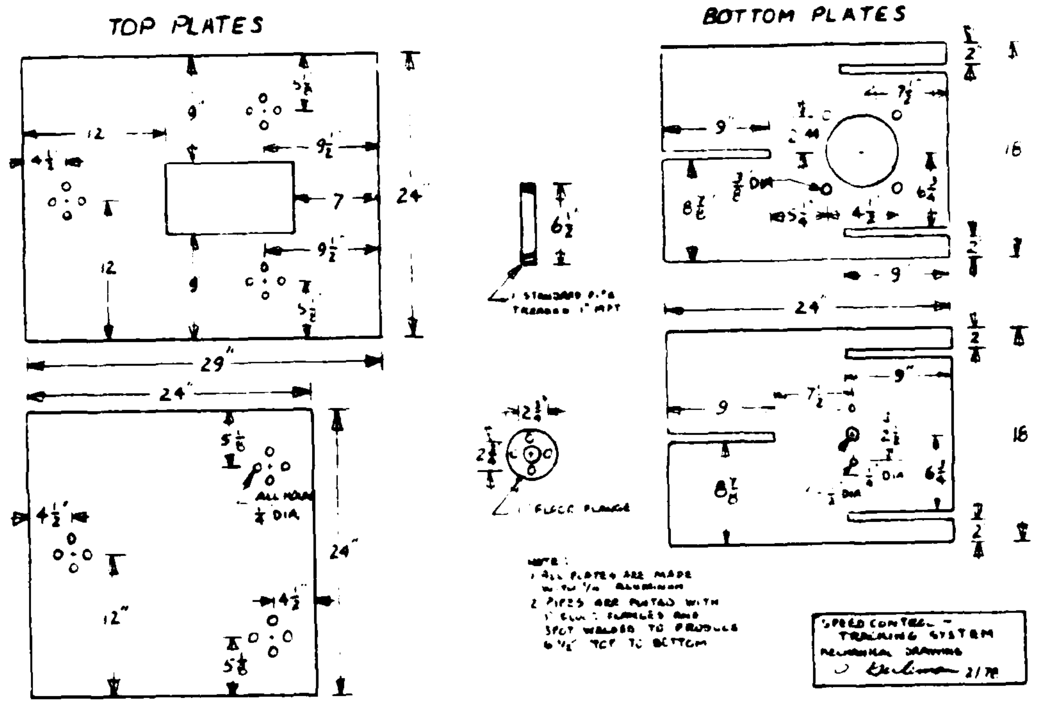

Figure 21

Mechanical Drawing of Suspension System
for Speed Control-Tracking System

armature voltage was proportional to the speed of the motor RPM, the voltmeter could be used to monitor the speed of the chain. A wiring diagram of this control system is presented in Figure 22, page 100. A photograph of the controls along with a portion of the chain leading to the motor driven gear sprocket and the foam ball are presented in Figure 23, page 101. The meter deflection was calibrated according to the velocity of the chain in centimeters per second. A description of the calibration procedure is included in Appendix E, page 138. Inadequate motor torque at low RPM prevented using the system at velocities lower than 10 centimeters per second. The functional range of the tracking system was 17 to 225 centimeters per second.

Speedometer Cane

Walking velocity on the circular course was controlled with a speedometer cane which the investigator or an assistant held as he walked with the subject. The cane is pictured in Figure 4, page 23. The cane was instrumented with a revolving wheel at the tip end and an electronic revolution counter on the shaft adjacent to the handle. A small rubber "O"-ring was placed around the perimeter of the wheel. The circumference of the wheel including the "O"-ring was 10 centimeters. A precision bearing was pressed into a hole drilled in the center of the wheel. Ten equally spaced holes were drilled around the perimeter

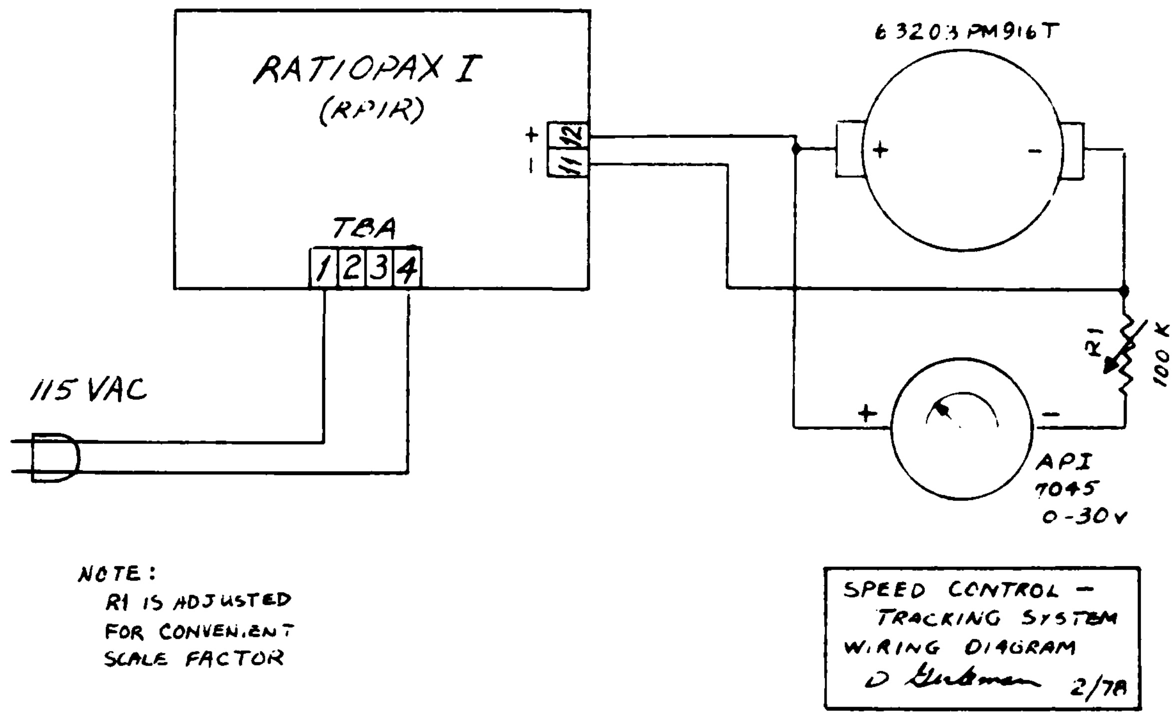

Figure 22

Operating Controls Wiring Diagram of
Speed Control-Tracking System

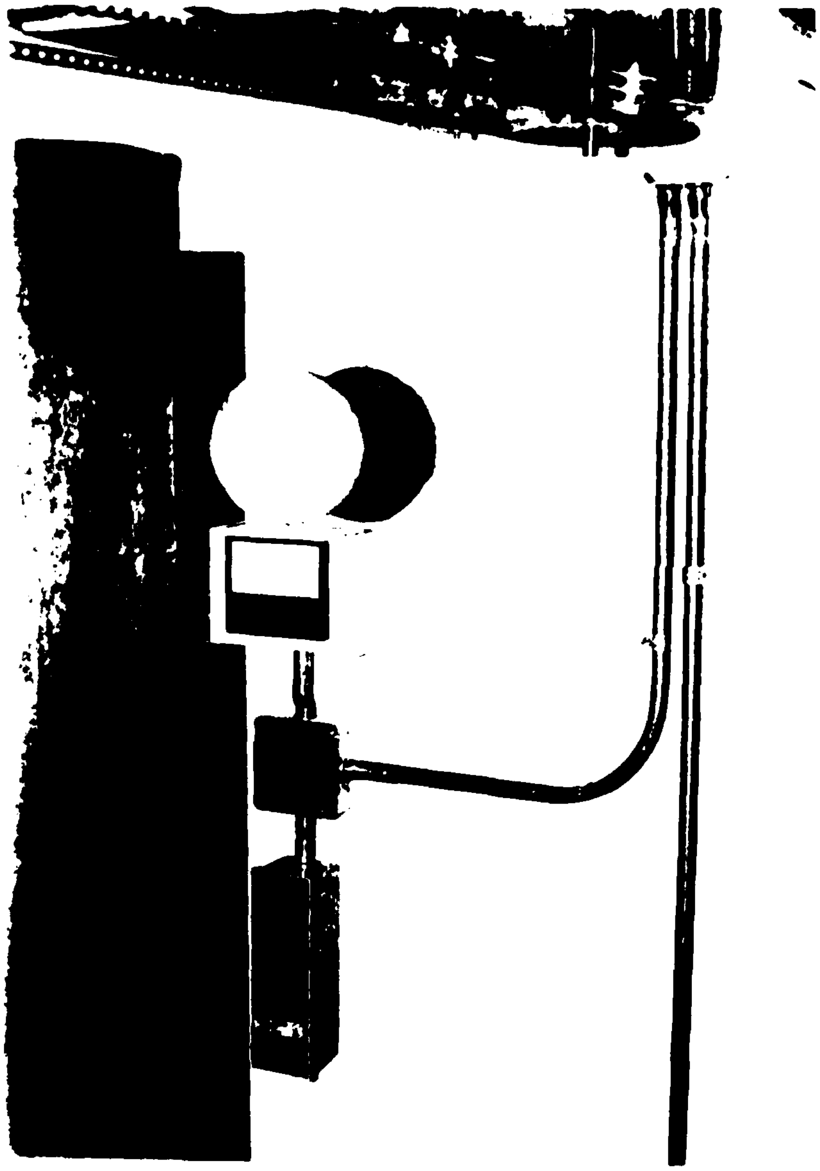

Figure 23

Operating Controls, Urethane Chain, Motorized Gear Sprocket, and Foam Ball of Speed Control-Tracking System

of the wheel. The wheel revolved in the saggital plane around a small metal axle shaft that was attached to the tip end of the cane. Two opposing metal plates, bolted to the tip end, served as mounting struts for the axle shaft. Lock nuts secured the threaded ends of the shaft to the metal plates. Two metal sleeves were placed concentrically on the axle on either side of the wheel to maintain the wheel in the center position between the mounting struts. The physical specifications of the wheel and its mounting are included in the mechanical drawing presented in Figure 24, page 103. A photograph of the tip end of the cane is presented in Figure 25, page 104. A miniature ultraviolet light source[a] was mounted on the inner side of one of the metal plates. The light source was positioned in line with the holes drilled around the perimeter of the wheel. A miniature photocell[a] was mounted on the opposing metal plate in line with the light source. This arrangement caused an interruption in light on the photocell as the wheel was pushed along the floor. These interruptions were counted by the electronics of the system for a one second interval and displayed in a digital array. This display represented the velocity of the wheel in centimeters per second. A nine volt battery served as the power source for the system. A wiring diagram for the

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[a] Texas Instruments, Chicago, Illinois 60646

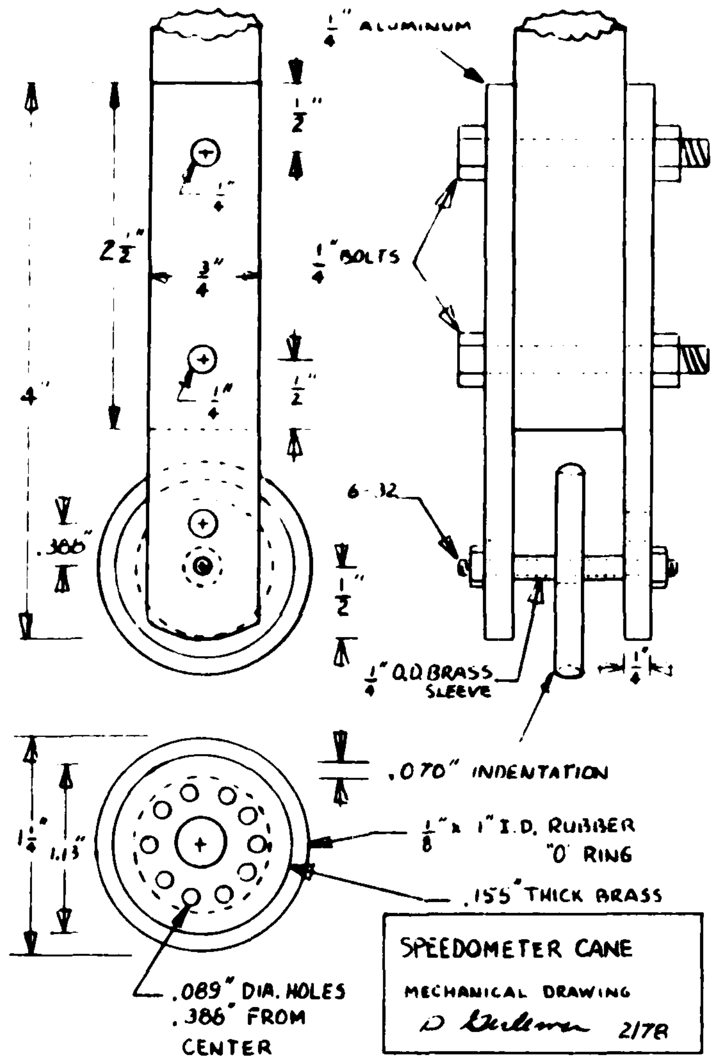


Figure 24

Mechanical Drawing of Speedometer Cane Wheel and Mounting

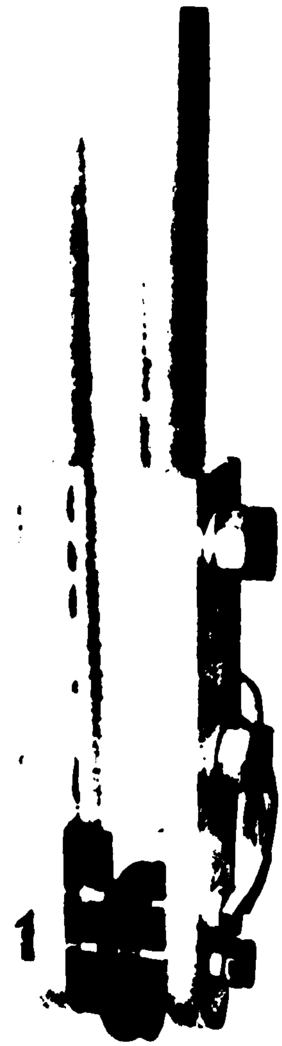


Figure 25

Detail of Speedometer
Cane Tip

electronics of the speedometer cane is presented in Figure 26, page 106. The accuracy of the speedometer cane was very high as is demonstrated in the calibration procedures described in Appendix E, page 110.

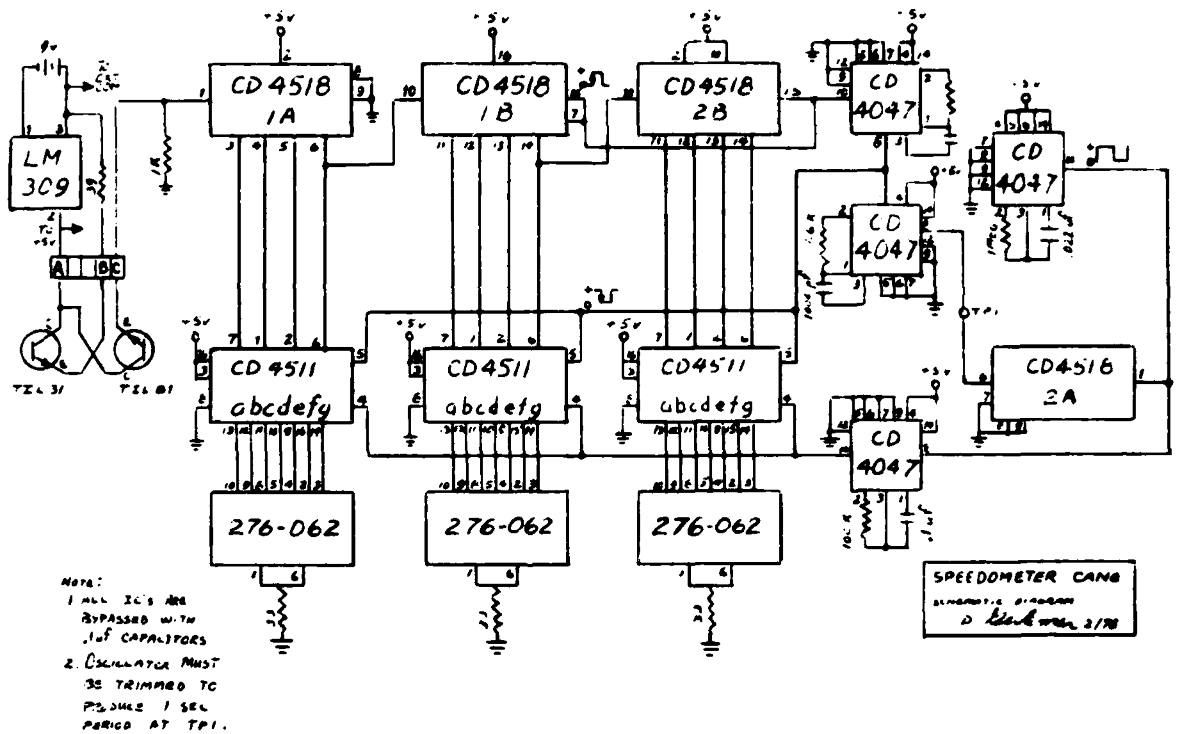


Figure 26

Wiring Diagram for
Speedometer Cane

APPENDIX E

CALIBRATION PROCEDURES

This appendix deals with the calibration procedures performed on the equipment used in the study. It was important that walking velocity be consistant between the three modes of level walking. Therefore, it was necessary that the devices used to regulate these velocities were accurate and reliable. The accuracy and reliability of the oxygen uptake equipment was equally as important. Specific methods of calibration were employed on the speed control-tracking system, speedometer cane, treadmill, oxygen and carbon dioxide gas analyzers, and the dry gas meter.

Speed Control-Tracking System

An electronic timer, photo relay, and two photocells were utilized in calibrating the speed of the speed control-tracking system. The electronic timer was a Hunter[a] model 120C and the photo relay a Hunter[a] model 335S. This equipment is presented in Figure 27, page 109. One photocell turned on the timer and the other turned the timer off when their respective light sources were interrupted. The photocells were arranged 192.1 centimeters apart at right angles to the urethane chain. Their positions near the chain

[a] Hunter Manufacturing Company, Inc., Iowa City, Iowa 52240

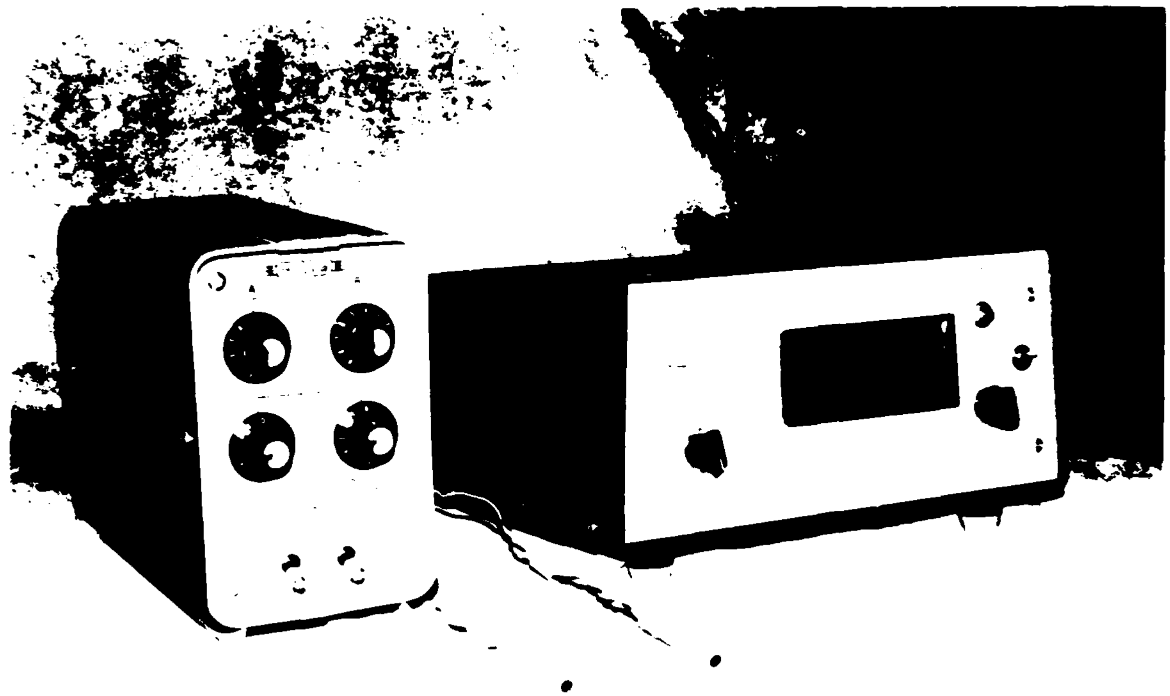


Figure 27

Photo Relay, Photocells, and Electronic Timer

enabled the rubber, foam ball attached to the chain to interrupt the light sources, actuating the photocells and subsequently controlling the electronic timer. In this manner the time necessary for the ball to travel the 192.1 centimeters between photocells was accurately recorded. This was performed for three trials at each of eight settings over the range of the meter and the speed of the tracking system motor. The mean time of the three trials was considered the most reliable measure and was used to compute the velocity of the ball and calibrate the meter. The values were expressed in centimeters per second. The mean times, standard deviations, and calculated velocities of each setting are presented in Table 13, page 111. The linearity of the system was 0.57% full scale.

Speedometer Cane

The speedometer cane was calibrated with the aid of the previously mentioned electronic timer, photo relay, photocells, and treadmill. The photocells were positioned to time the revolutions of the treadmill belt. The belt was measured to be 310.90 centimeters in circumference. The wheel at the tip of the cane was placed on the revolving treadmill belt and held in a steady position. The digital display of the speedometer cane was read as the treadmill belt moved through twenty-five revolutions. The velocity of the belt was calculated by noting the time necessary for

Table 13

Calibration of Speed Control-Tracking System: Mean Times, Standard Deviations, and Calculated Velocities[a]

Mean Time (sec)	Standard Deviation	Calculated Velocity (cm/sec)
4.605	.0171	41.72
2.826	.0076	67.98
2.054	.0040	93.52
1.603	.0025	119.84
1.305	.0000	147.20
1.108	.0026	173.38
0.965	.0015	199.07
0.862	.0006	222.85

[a] Velocity calculated over a distance of 192.1 cm.

the twenty-five revolutions and the distance that the belt had moved during that time. This was repeated for three trials at each of four velocity settings. The mean time for the three trials was used to calculate the velocity of the belt. The mean value of the digitally displayed velocity of the speedometer cane was compared with the mean calculated velocity of the treadmill belt. These comparisons with the respective percent errors are presented in Table 14, page 113.

The speedometer cane was also validated on its ability to regulate walking velocity by use in walking trials. The investigator walked down a hallway using the cane to control his velocity and attempted to follow the seven velocities used in the study. Five trials were used at each velocity. The time necessary to walk twenty meters of the hallway was recorded by the priviously mentioned photocells and electronic timer. The mean time of the five trials was used to compute the walking velocity. The desired velocity, the calculated velocity, and the respective percent errors are presented in Table 15, page 114.

Treadmill

The velocity of the treadmill was calibrated with the aid of the previously mentioned electronic timer, photo relay, and photocells. The photocells were positioned near the treadmill belt in order to time the revolutions. The

Table 14

Speedometer Cane Calibration on Treadmill: Mean Times, Standard Deviations, Mean Treadmill and Cane Velocities[a], and Percent Errors

Mean Time (sec)	Standard Deviation	Treadmill Velocity (cm/sec)	Cane Velocity (cm/sec)	Percent Error
190.33	.495	40.84	41.0	0.39
88.86	.347	87.47	88.5	1.18
56.91	.409	136.57	137.5	0.68
42.02	.010	184.97	186.0	0.56

[a] Velocity calculated over a distance of 77.724 meters.

Table 15

Speedometer Cane Walking Trials: Mean Times, Standard Deviations, Desired Velocity, Calculated Velocity[a], and Percent Errors

Mean Time (sec)	Standard Deviation	Desired Velocity (cm/sec)	Calculated Velocity (cm/sec)	Percent Error
44.67	.635	44.70	44.97	0.60
29.89	.357	67.06	66.91	0.22
22.76	.224	89.41	87.87	1.72
18.17	.112	111.76	110.07	1.51
15.21	.079	134.11	131.49	1.95
12.86	.110	156.46	155.52	0.60
11.38	.103	178.82	175.75	1.72

[a] Velocity calculated over a distance of 20 meters.

measured circumference of the belt was 510.90 centimeters. The treadmill was run at the seven velocities used in the study. Three trials were timed at each velocity. Each trial consisted of twenty-five revolutions of the belt. The mean time for the three trials was used in the calculation of velocity at each setting. The desired velocity, calculated velocity, and the respective percent errors are presented in Table 16, page 116.

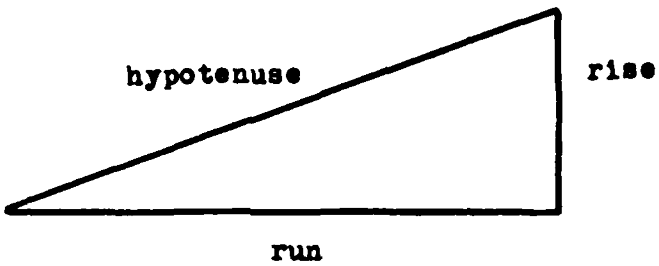
The treadmill was also calibrated according to the percent incline, or grade, which was used in the maximal exercise tolerance test. The percent grade was defined as the ratio of rise to run multiplied by 100 (% grade = rise /run x 100). For measurement purposes the side view of the treadmill was equated to a right triangle when inclined. The hypotenuse was a fixed distance and could be measured directly. Similarly the amount of rise could be measured directly. The amount of run, or base of the triangle, was calculated using the Pythagorean Theorem, $a^2 = b^2 + c^2$. The method just described is schematically represented in Figure 28, page 117. The procedure was performed throughout the range of the meter on the treadmill. The largest descrepancy was noted when the treadmill was adjusted to a meter reading of 17% grade. The calculated grade at this setting was actually 18%. For every other grade beyond this setting the calculated percent grade was 1% over the value given on the meter.

Table 16

Treadmill Velocity Calibration: Mean Times, Standard Deviations, Desired Velocity, Calculated Velocity[a], and Percent Errors

Mean Times (sec)	Standard Deviation	Desired Velocity (cm/sec)	Calculated Velocity (cm/sec)	Percent Error
184.64	1.008	44.70	42.09	5.84
118.87	0.020	67.06	65.38	2.50
86.97	0.012	89.41	89.37	0.04
68.72	0.310	111.76	113.10	1.20
56.58	0.010	134.11	137.37	2.43
48.17	0.012	156.46	161.36	3.13
42.21	0.000	178.82	184.13	2.97

[a] Velocity calculated over a distance of 77.724 meters.



hypotenuse = 180.34 cm.

$$\text{run} = \sqrt{\text{hypotenuse}^2 - \text{rise}^2}$$

$$\%\ \text{incline} = \frac{\text{rise}}{\text{run}} \times 100$$

Figure 28

Treadmill Incline Calibration

Oxygen and Carbon Dioxide Gas Analyzers

The oxygen (O_2) and carbon dioxide (CO_2) gas analyzers were calibrated prior to testing each subject. Each analyzer was checked with known gases. The O_2 analyzer was calibrated with room air which was assumed to be 20.9% O_2, then checked with a known gas containing 10.5% O_2. The CO_2 analyzer was first set on zero using 100% nitrogen, and then calibrated with a known gas containing 7.96% CO_2.

Dry Gas Meter

The dry gas meter was calibrated at the flow rate used in the study by drawing known quantities of air through the meter from a Collins P-1700 Gasometer. This spirometer is pictured in Figure 29, page 119. Three trials were performed at five different volumes. The mean volume observed from the gas meter for the three trials was used in the calculation of a regression equation, $Y = 0.9813X - 0.083$ ($r = .99$) Gas volume measurements were obtained by substituting the gas meter reading, the differences between the final and initial meter reading for each trial, for the "X" value in the equation. The measured volume of air from the gasometer, the observed volume, and the standard deviations are presented in Table 17, page 120.

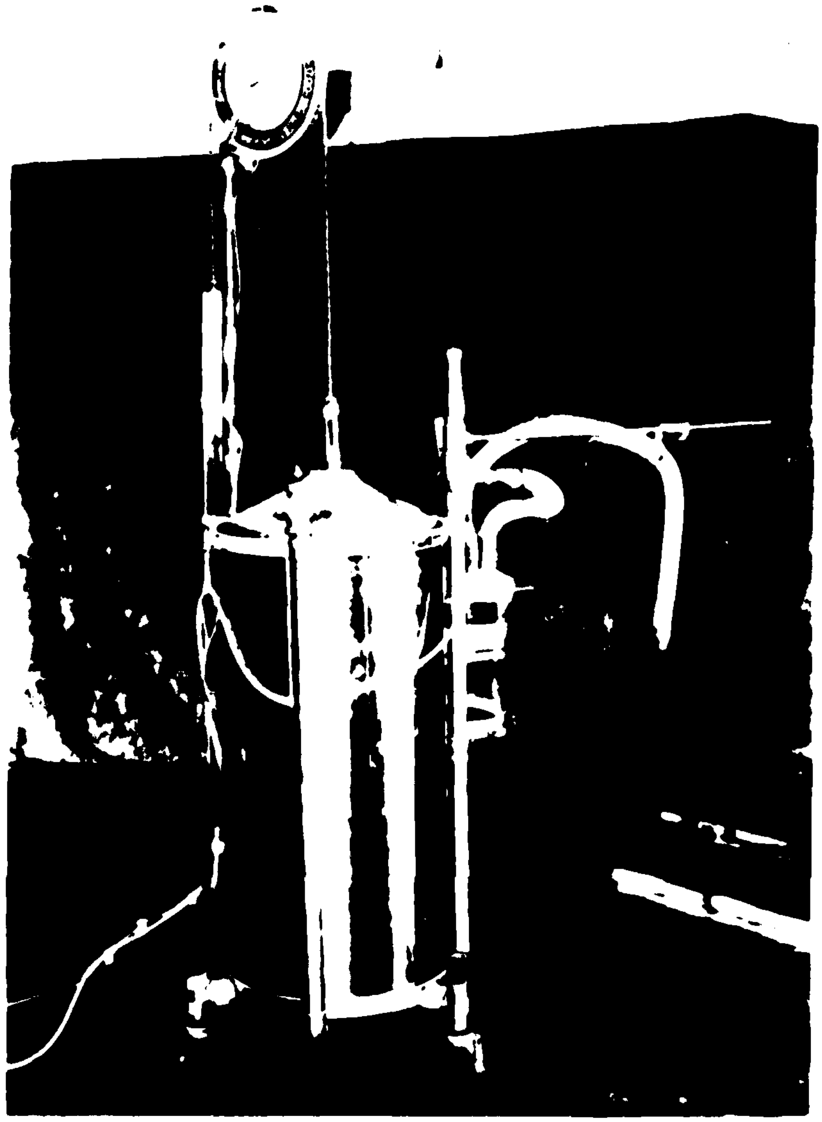


Figure [illegible]

Collins P-1700 Gasometer

Table 17

Dry Gas Meter Calibration: Known Volumes, Mean Measured Volumes, and Standard Deviations

Known Volume (liters)	Measured Volume (liters)	Standard Deviation
13.32	13.65	.040
26.64	27.19	.045
39.96	40.87	.050
53.28	54.41	.046
66.60	67.91	.046

APPENDIX F

CALCULATOR PROGRAM

All calculations for determining oxygen consumption were performed on the Hewlett Packard model 97 calculator. To minimize possibilities for errors the calculator received as much raw data as possible, therefore reducing the need for extraneous calculations. The parameters necessary for determining oxygen uptake were systematically entered into the calculator storage facilities. The order in which they were entered corresponded to their location on the appropriate data work sheet. (Examples of these data sheets are presented in Appendix J, pages 144 and 145.) The parameters entered were the following:

1. Time, in seconds, of expired air collection;
2. Percentage of expired oxygen;
3. Percentage of expired carbon dioxide;
4. The STPD conversion factor;
5. The subjects body weight, in kilograms; and
6. The volume of expired air.

The calculator corrected the volume of expired air by using the equation derived during the calibration of the dry gas meter, as previously described in Appendix E, page 118. The calculator then corrected this volume to standard conditions (STPD) by multiplying by the conversion factor. By using the amount of time reported for collection of the

expired air, the calculator converted this standard volume into a minute volume ($\dot{V}_E$), which was used in further calculations. The formulas for deriving oxygen uptake previously described in Chaper III, page 46 were used by the calculator. After the computations were complete, the calculator printed the following:

1. The minute volume ($\dot{V}_E$);
2. Oxygen uptake in liters per minute;
3. Oxygen uptake in milliliters per kilogram per minute;
4. Oxygen uptake in metabolic equivalents (MET);
5. The respiratory quotient.

The complete program for the Hewlett Packard model 97 calculator is presented in Figure 30, page 124.

001	*LBLA	21 11
002	ENT↑	-21
003	.	-62
004	9	09
005	2	02
006	1	01
007	3	03
008		-55
009	.	-62
010	.	-62
011	0	00
012	3	03
013	7	07
014	-	-45
015	RCL4	36 04
016	×	-35
017	5	05
018	2	02
019		-35
020	RCL1	36 01
021	÷	-24
022	DSP2	-63 02
023	PRTX	-14
024	STO6	35 06
025	RCL5	36 05
026	RCL2	36 02
027	1	01
028	0	00
029	0	00
030	÷	-24
031		-35
032	STO7	35 07
033	1	01
034	RCL2	36 02
035	1	01
036	0	00
037	0	00
038	÷	-24
039	-	-45
040	RCL3	36 03
041	1	01
042	0	00
043	0	00
044	÷	-24
045	-	-45
046	RCL5	36 05
047	×	-35
048	.	-62
049	2	02
050	6	06
051	4	04
052	8	08
053		-35
054	RCL7	36 07
055	-	-45
056	PRTX	-14
057	STO8	35 08
058	1	01
059	0	00
060	0	00
061	2	02
062	×	-35
063	RCL5	36 05
064	÷	-24
065	PRTX	-14
066	3	03
067	.	-62
068	5	05
069	÷	-24
070	PRTX	-14
071	RCL6	36 06
072	RCL8	36 08
073	1	01
074	0	00
075	0	00
076	÷	-24
077	×	-35
078	RCL8	36 08
079	÷	-24
080	SPC	16-11
081	PRTX	-14
082	RTN	24
083	R/S	51

Figure 30

Calculator Program for Oxygen Uptake and Respiratory Quotient

APPENDIX G

STANDARD TEMPERATURE AND PRESSURE, DRY CONVERSION FACTORS

Table 18

STPD Conversion Factors

FACTORS FOR REDUCING VOLUME OF MOIST GAS TO VOLUME OCCUPIED BY DRY GAS AT 0°, 760 MM

OBSERVED BAROMETRIC READING, UNCORRECTED FOR TEMPERATURE	15°	16°	17°	18°	19°	20°	21°	22°	23°	24°	25°	26°	27°	28°	29°	30°	31°	32°
700	0.855	851	847	[illegible]	[illegible]	[illegible]	829	825	821	816	812	[illegible]	[illegible]	797	793	[illegible]	783	778
702	857	[illegible]	849	845	[illegible]	836	832	827	823	818	814	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	785	780
704	860	856	852	847	843	[illegible]	834	830	825	821	816	812	[illegible]	802	797	[illegible]	787	783
706	862	858	854	850	845	841	837	832	828	823	819	814	810	[illegible]	[illegible]	795	790	785
708	865	861	856	852	848	843	839	834	[illegible]	825	821	816	812	807	802	797	792	787
710	867	863	859	855	850	846	842	837	833	828	824	819	814	809	804	[illegible]	795	790
712	870	866	861	857	853	848	844	839	836	830	826	821	817	812	807	802	797	792
714	872	868	864	859	855	851	846	842	837	833	828	821	819	814	809	804	799	794
716	875	871	866	862	858	853	849	844	840	835	831	826	822	816	812	807	802	797
718	877	873	869	864	860	856	851	847	842	838	833	828	824	819	814	809	804	799
720	880	876	871	867	863	858	854	849	845	840	836	831	826	821	816	812	807	802
722	882	877	874	869	865	861	856	852	847	843	838	833	829	824	819	814	809	804
724	885	880	876	872	867	863	858	854	849	845	840	835	831	826	821	816	811	806
726	887	883	879	874	870	866	861	856	852	847	843	838	833	829	824	818	813	808
728	890	886	881	877	872	868	863	859	854	850	845	840	836	831	826	821	816	811
730	892	888	884	879	875	871	866	861	857	852	847	843	838	833	828	823	818	813
732	895	890	886	882	877	873	868	864	859	854	850	845	840	836	831	825	820	815
734	897	893	889	884	880	875	871	866	862	857	852	847	843	838	833	828	823	818
736	900	895	891	887	882	878	873	869	864	859	855	850	845	840	835	830	825	820
738	902	898	894	[illegible]	885	880	876	871	866	862	857	852	848	843	838	833	828	822
740	905	900	896	892	887	883	878	874	869	864	860	855	850	845	840	835	830	825
742	907	903	898	894	890	885	881	876	871	867	862	857	852	847	842	837	832	827
744	910	905	901	897	892	888	883	878	874	869	864	859	855	850	845	840	834	829
746	912	908	903	899	895	890	886	881	876	872	867	862	857	852	847	842	837	832
748	915	910	906	901	897	892	888	883	879	874	869	864	860	854	850	845	839	834
750	917	913	908	904	900	895	890	886	881	876	872	867	862	857	852	847	842	837
752	920	915	911	906	902	897	893	888	883	879	874	869	864	859	854	849	844	839
754	922	918	913	[illegible]	904	900	895	891	886	881	876	872	867	862	857	852	846	841
756	925	920	916	911	907	902	898	893	[illegible]	883	879	874	869	864	859	854	849	844
758	927	923	918	914	909	905	900	896	891	886	881	876	872	866	861	856	851	846
760	930	925	921	916	912	907	902	[illegible]	893	888	[illegible]	879	874	869	864	[illegible]	854	848
762	932	928	923	919	914	910	905	900	896	891	886	881	876	871	866	861	856	851
764	935	930	926	921	916	912	907	903	[illegible]	893	888	884	879	874	869	864	858	853
766	937	933	928	924	919	915	910	905	900	[illegible]	891	[illegible]	881	876	871	866	861	855
768	940	935	931	926	922	917	912	[illegible]	903	[illegible]	[illegible]	[illegible]	883	878	873	[illegible]	863	858
770	942	938	[illegible]	928	924	919	915	910	905	[illegible]	[illegible]	891	[illegible]	881	876	871	865	860
772	945	940	[illegible]	931	926	922	917	912	[illegible]	903	[illegible]	893	888	883	878	873	868	862
774	947	943	[illegible]	[illegible]	929	924	920	915	910	905	901	[illegible]	[illegible]	886	880	875	870	865
776	950	[illegible]	941	[illegible]	931	927	[illegible]	91[illegible]	912	[illegible]	903	[illegible]	[illegible]	[illegible]	[illegible]	878	872	867
778	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	910	[illegible]	900	[illegible]	890	[illegible]	[illegible]	875	869
780	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	927	922	917	[illegible]	[illegible]	[illegible]	[illegible]	892	887	882	877	872

APPENDIX H

SUBJECT AGE AND WEIGHT

Table 19

Subject Number, Age, and Weight (kilograms) with Means and Standard Deviations

Number	Age	Weight
1	25	73.07
2	27	87.72
3	26	65.12
4	31	75.97
5	30	67.90
6	29	84.14
7	32	72.39
8	36	71.42
9	32	83.75
10	32	67.73
11	35	69.20
12	23	82.50
13	18	61.08
14	27	73.98
15	23	67.62
16	37	96.12
17	32	63.98
18	36	91.52
19	30	99.20
20	22	78.64

Table 19 - continued

Number	Age	Weight
21	25	68.98
22	24	74.49
23	23	70.96
24	30	85.00
25	32	67.44
26	22	86.65
27	23	77.73
28	34	90.34
29	24	89.49
30	28	70.74
Mean	28.3	77.16
Standard Deviation	4.99	10.17

APPENDIX I

INDIVIDUAL SIMPLE LINEAR REGRESSION ANALYSES

Table 20

Individual Slopes, Intercepts, R^2, F, and p Values for Simple Linear Regression Analysis of Oxygen Uptake versus Velocity Squared for Segmental Walking

Subject Number	Slope	Intercept	R^2	F	p
1	.00127	5.926	.98	298.19	.0001
2	.00120	5.750	.97	152.66	.0001
3	.00150	5.733	.98	260.63	.0001
4	.00139	4.139	.97	142.68	.0001
5	.00147	4.763	.97	169.05	.0001
6	.00131	4.669	.97	139.97	.0001
7	.00129	5.854	.97	144.88	.0001
8	.00142	4.818	.91	50.03	.0009
9	.00119	5.982	.97	174.72	.0001
10	.00171	6.564	.98	238.15	.0001
11	.00115	5.370	.94	74.32	.0003
12	.00140	4.586	.94	74.32	.0003
13	.00146	4.349	.91	50.13	.0009
14	.00150	5.934	.97	161.20	.0001
15	.00091	6.854	.86	30.31	.0027
16	.00097	5.175	.92	58.17	.0006
17	.00158	4.528	.90	46.51	.0010
18	.00146	3.099	.95	102.88	.0002
19	.00149	3.796	.99	418.80	.0001
20	.00129	5.103	.98	244.94	.0001

Table 20 - continued

Subject Number	Slope	Intercept	R^2	F	p
21	.00166	6.696	.98	194.03	.0001
22	.00110	4.815	.97	153.09	.0001
23	.00186	5.317	.99	389.55	.0001
24	.00166	4.177	.95	82.95	.0008
25	.00131	5.788	.96	137.40	.0001
26	.00108	5.597	.99	377.89	.0001
27	.00117	5.487	.96	137.70	.0001
28	.00130	5.050	.97	145.82	.0001
29	.00149	4.854	.98	223.57	.0001
30	.00130	5.770	.93	67.98	.0004
Mean	.00136	5.218	.96		
S.D.	.00022	0.861	.03		

Table 21

Individual Slopes, Intercepts, R^2, F, and p Values for Simple Linear Regression Analysis of Oxygen Uptake versus Velocity Squared for Circular Walking

Subject Number	Slope	Intercept	R^2	F	p
1	.00077	6.092	.98	236.81	.0001
2	.00080	6.566	.99	907.84	.0001
3	.00095	6.682	.99	1113.35	.0001
4	.00094	6.556	.98	285.31	.0001
5	.00083	5.019	.98	223.19	.0001
6	.00099	4.821	.99	1568.10	.0001
	.00105	5.139	.98	246.52	.0001
8	.00089	5.870	.99	474.59	.0001
9	.00112	6.015	.98	234.18	.0001
10	.00107	6.863	.97	166.46	.0001
11	.00100	5.386	.99	719.20	.0001
12	.00096	5.314	.97	176.83	.0001
13	.00104	6.725	.99	1282.88	.0001
14	.00119	6.007	.99	557.45	.0001
15	.00098	7.828	.99	593.20	.0001
16	.00068	6.118	.99	7763.45	.0001
17	.00090	9.200	.95	93.86	.0002
18	.00100	6.289	.99	472.39	.0001
19	.00102	5.348	.98	235.11	.0001
20	.00075	5.095	.99	2152.49	.0001

Table 21 - continued

Subject Number	Slope	Intercept	R^2	F	p
21	.00107	5.888	.99	1525.35	.0001
22	.00082	7.231	.99	360.87	.0001
23	.00095	6.539	.98	238.69	.0001
24	.00099	5.251	.97	191.33	.0001
25	.00089	6.492	.98	321.25	.0001
26	.00092	5.521	.99	485.68	.0001
27	.00081	5.875	.99	473.08	.0001
28	.00084	6.115	.99	1828.80	.0001
29	.00112	5.201	.99	651.44	.0001
30	.00093	5.813	.98	223.93	.0001
Mean	.00094	6.097	.98		
S.D.	.00012	0.918	.01		

Table 22

Individual Slopes, Intercepts, R^2, F, and p Values for Simple Linear Regression Analysis of Oxygen Uptake versus Velocity Squared for Treadmill Walking

Subject Number	Slope	Intercept	R^2	F	p
1	.00094	5.382	.95	103.22	.0002
2	.00086	5.677	.96	114.88	.0001
3	.00103	6.549	.99	393.31	.0001
4	.00095	5.598	.97	144.82	.0001
5	.00108	4.135	.99	347.42	.0001
6	.00097	6.016	.96	107.73	.0001
7	.00102	5.828	.99	424.41	.0001
8	.00073	6.877	.98	301.58	.0001
9	.00117	5.426	.98	335.88	.0001
10	.00094	7.241	.99	599.63	.0001
11	.00089	6.151	.97	147.31	.0001
12	.00087	5.716	.98	298.30	.0001
13	.00104	7.087	.98	192.57	.0001
14	.00113	6.671	.94	84.37	.0003
15	.00107	5.543	.98	224.24	.0001
16	.00075	5.513	.98	222.54	.0001
17	.00053	4.059	.99	371.20	.0001
18	.00095	5.167	.97	184.94	.0001
19	.00090	6.455	.96	118.38	.0001
20	.00094	5.693	.98	246.43	.0001

Table 22 - continued

Subject Number	Slope	Intercept	R^2	F	p
21	.00104	6.469	.99	633.87	.0001
22	.00091	5.122	.99	368.06	.0001
23	.00086	6.725	.98	284.58	.0001
24	.00078	7.134	.96	116.94	.0001
25	.00100	6.735	.95	93.89	.0002
26	.00087	6.119	.98	222.75	.0001
27	.00102	6.881	.98	194.06	.0001
28	.00084	5.698	.98	247.23	.0001
29	.00096	4.884	.99	356.90	.0001
30	.00095	5.714	.99	173.98	.0001
Mean	.00093	5.942	.98		
S.D.	.00013	0.820	.01		

Table 23

Individual Slopes, Intercepts, R^2, F, and p Values for Simple Linear Regression Analysis of Oxygen Uptake versus Heart Rate for Segmental Walking

Subject Number	Slope	Intercept	R^2	F	p
1	.393	-18.665	.99	598.69	.0001
2	.315	-17.589	.91	48.13	.0010
3	.354	-17.584	.97	152.19	.0001
4	.380	-16.153	.96	110.00	.0001
5	.456	-28.120	.98	263.21	.0001
6	.438	-25.330	.98	218.72	.0001
7	.413	-21.262	.95	97.74	.0002
8	.497	-30.244	.98	297.96	.0001
9	.324	-18.773	.92	55.49	.0007
10	.353	-16.764	.94	79.29	.0003
11	.306	-16.180	.99	390.00	.0001
12	.526	-45.231	.58	6.90	.0467
13	.400	-27.536	.88	38.45	.0016
14	.400	-20.732	.99	380.21	.0001
15	.309	-10.766	.83	24.34	.0043
16	.337	-17.339	.96	133.85	.0001
17	.338	-21.162	.96	114.12	.0001
18	.502	-28.434	.98	218.40	.0001
19	.376	-26.407	.97	163.26	.0001
20	.501	-35.562	.94	77.11	.0003

Table 23 - continued

Subject Number	Slope	Intercept	R^2	F	p
21	.439	-29.535	.96	109.66	.0001
22	.490	-25.041	.98	201.57	.0001
23	.391	-26.604	.99	432.02	.0001
24	.443	-35.367	.96	89.43	.0007
25	.314	- 8.355	.97	146.88	.0001
26	.374	-22.939	.88	36.91	.0017
27	.507	-35.283	.94	72.04	.0004
28	.405	-26.601	.95	93.49	.0002
29	.309	-17.957	.98	235.70	.0001
30	.365	-18.606	.90	46.56	.0010
Mean	.398	-23.537	.94		
S.D.	.068	7.978	.08		

Table 24

Individual Slopes, Intercepts, R^2, F, and p Values
for Simple Linear Regression Analysis of
Oxygen Uptake versus Heart Rate
for Circular Walking

Subject Number	Slope	Intercept	R^2	F	p
1	.302	-11.541	.91	50.90	.0008
2	.203	- 5.534	.97	156.80	.0001
3	.340	-18.167	.98	250.59	.0001
4	.343	-15.792	.97	182.97	.0001
5	.380	-21.157	.84	26.38	.0037
6	.314	-16.668	.98	211.23	.0001
7	.343	-15.100	.92	59.23	.0006
8	.341	-17.660	.94	73.82	.0004
9	.269	-12.972	.98	308.03	.0001
10	.342	-17.970	.99	350.84	.0001
11	.379	-21.724	.94	74.00	.0004
12	.284	-14.925	.98	191.63	.0001
13	.344	-18.180	.97	153.67	.0001
14	.360	-17.128	.95	95.87	.0002
15	.272	- 7.083	.99	410.77	.0001
16	.222	- 9.677	.81	21.14	.0059
17	.267	-15.746	.82	22.69	.0050
18	.388	-24.165	.96	123.23	.0001
19	.270	-17.206	.95	97.55	.0002
20	.291	-15.460	.90	45.27	.0011

Table 24 - continued

Subject Number	Slope	Intercept	R^2	F	p
21	.291	-12.486	.88	37.61	.0017
22	.344	-13.460	.86	30.86	.0026
23	.314	-21.831	.97	161.61	.0001
24	.281	-15.895	.94	86.56	.0002
25	.291	- 7.538	.98	280.97	.0001
26	.406	-23.665	.90	43.48	.0012
27	.379	-25.957	.99	1689.60	.0001
28	.308	-15.828	.89	40.96	.0014
29	.279	-17.273	.99	834.33	.0001
30	.311	-13.056	.93	67.50	.0004
Mean	.315	-16.028	.94		
S.D.	.048	4.907	.05		

Table 25

Individual Slopes, Intercepts, R^2, F, and p Values for Simple Linear Regression Analysis of Oxygen Uptake versus Heart Rate for Treadmill Walking

Subject Number	Slope	Intercept	R^2	F	p
1	.311	-12.822	.98	269.65	.0001
2	.283	-12.301	.98	254.44	.0001
3	.325	-13.307	.98	182.39	.0002
4	.444	-23.560	.98	255.98	.0001
5	.397	-21.728	.94	80.22	.0003
6	.422	-22.820	.92	58.41	.0006
7	.347	-12.653	.99	736.42	.0001
8	.523	-33.016	.80	20.26	.0064
9	.382	-23.631	.95	93.44	.0002
10	.284	-13.761	.99	374.30	.0001
11	.371	-24.951	.97	181.11	.0001
12	.518	-41.055	.57	6.60	.0501
13	.348	-18.191	.88	35.62	.0019
14	.393	-19.994	.98	291.41	.0001
15	.312	-12.028	.96	106.81	.0001
16	.323	-17.722	.91	52.37	.0008
17	.257	-20.357	.80	19.72	.0068
18	.536	-32.246	.93	65.18	.0005
19	.362	-24.464	.87	34.00	.0021
20	.369	-20.418	.97	150.08	.0001

Table 25 - continued

Subject Number	Slope	Intercept	R^2	F	p
21	.403	-28.929	.80	19.75	.0067
22	.461	-22.513	.95	86.80	.0002
23	.400	-30.422	.94	82.95	.0003
24	.225	-10.835	.95	90.36	.0002
25	.312	- 9.336	.95	97.52	.0002
26	.398	-25.974	.94	84.46	.0003
27	.447	-35.246	.90	43.06	.0012
28	.420	-25.895	.96	138.56	.0001
29	.353	-24.330	.98	227.11	.0001
30	.382	-22.665	.90	45.69	.0011
Mean	.377	-21.906	.92		
S.D.	.075	7.828	.09		

APPENDIX J

DATA WORK SHEETS

CIRCULAR WALKING

Subject Name ______________________________ (last) (first)　　Number ________

Date ______________　　Wt. ________　　Age ________

Barometric Pressure ______________　　Room Temp. ____________

	Speed							
	Rest	1.0	1.5	2.0	2.5	3.0	3.5	4.0	Pre M.A.P.
heart rate									
collection time (seconds)									
FEO_2									
$FECO_2$									
STPD Factor									
Gas Temp.									
2nd Meter Reading									
1st Meter Reading									
Difference									
$\dot{V}_E$ (STPD)									
l/min									
ml/kg-min									
M.E.T.									
R.Q.									

TREADMILL EXERCISE TEST

Name ______________________________ Number __________
          last   first

Date __________________ weight __________ age __________

Barometric Pressure ______________ Room Temp. ______________

Age Predicted Max. H.R. (220-age) ______________

Treadmill Speed ______________

	% incline							
	2	4	6	8	10	12	14	16
heart rate								
collection time (seconds)								
FEO_2								
$FECO_2$								
STPD Factor								
Gas Temp.								
2nd Meter Reading								
1st Meter Reading								
Difference								
$\dot{V}_E$ (STPD)								
l/min								
ml/kg-min								
M.E.T.								
R.Q.								

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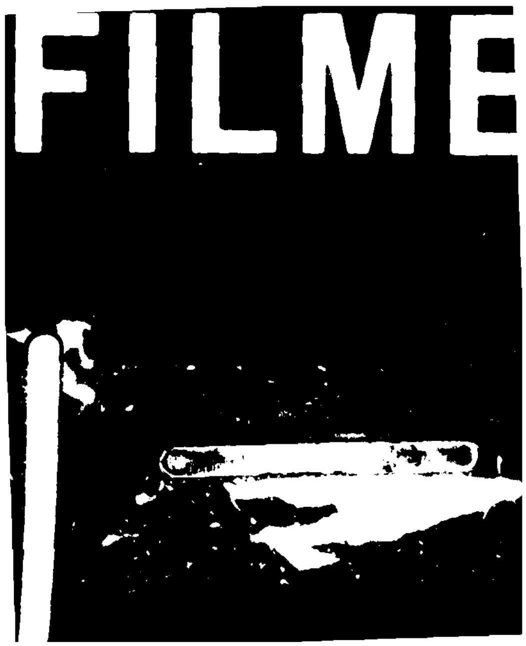
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